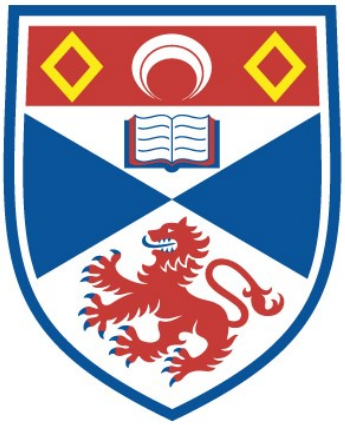
USE OF INORGANIC CARBON IN THE PHOTOSYNTHESIS OF AQUATIC MACROPHYTES AND MICROALGAE

E. Dale Allen

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews



1977

Use of Inorganic Carbon in the Photosynthesis of Aquatic Macrophytes and Microalgae.

by

E. Dale Allen

A thesis submitted to the University of St. Andrews for the degree of Doctor of Philosophy

Department of Botany
University of St. Andrews

September 1977

DECLARATION

I hereby declare that this thesis is of my own composition, that it is based on an accurate record of work carried out by me, and that it has not been previously presented in application for a higher degree.

E. Dale Allen

St. Andrews, October 1977.

CERTIFICATE

I certify that E. Dale Allen has spent 12 terms of research under my direction, that he has fulfilled the conditions of Ordinance General No. 12 and Resolution of the University Court 1967 No. 1, and that he is qualified to submit the accompanying thesis in application for the degree of Doctor of Philosophy.

D.H.N. Spence

St. Andrews, October 1977.

ACKNOWLEDGEMENTS

I should like to thank Professor D.H.N. Spence for his encouragement and his willingness to lend an ear to my ideas and problems, and for his companionship on numerous field expeditions above and below the water.

I also wish to thank the Natural Environment Research Council for the award of a research grant which made this work possible.

E.D.A.
October '77

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PART I

UTILIZATION OF INORGANIC CARBON BY AQUATIC PLANTS.

INTRODUCTION

Autotrophic organisms living submerged in freshwaters are presented with an exogenous carbon supply which is much more widely variable in quantity and form than that to which their aerial counterparts are exposed. It is likely that the ability of a submerged aquatic plant to utilize this variable carbon supply greatly influences the ecological niche it can occupy. Populations of some aquatic plants can cause severe depletion of the carbon supply and so induce intense competition for the remainder. To assess the performance of different species under such stress conditions, something must be known of their capacities to utilize carbon in its various forms.

Since Hassack (1888) first suggested that water plants might utilize exogenous bicarbonate in photosynthesis, indirect methods have been employed to differentiate between the ability or inability to use bicarbonate amongst some macrophytes (Ruttner 1947, 1948; Steemann Nielsen, 1947) and algae (Österlind, 1951, 1952; Felföldy, 1962, 1965; Tregunna & Thomas, 1968; and Talling 1976).

With more direct methods involving uptake of $^{14}CO_2$ and $H^{14}CO_3^-$, Raven (1968), Smith (1968) & Lucas (1975) established that bicarbonate is used photosynthetically by, respectively, *Hydrodictyon africanum* and several Characean species, including *Chara corallina*. Borowitzka & Larkum (1976) have used this method to study photosynthesis and calcification in *Halimeda*. Denny & Weeks (1970) compared observed and calculated cell membrane potentials of detached leaves of *Potamogeton schweinfurthii* in various bicarbonate solutions and produced strong evidence for at least partially active transport of HCO_3^- coupled to photosynthesis. Raven (1968) showed that bicarbonate uptake in *Hydrodictyon africanum* depended on a specific light reaction involving Photosystem II, and that photosynthesis with bicarbonate in this species was more sensitive to DCMU inhibition than was CO_2 fixation. A detailed review of exogenous carbon sources in photosynthesis is provided by Raven (1970).

Evidence presented by Briggs & Whittingham (1952), Österlind (1951, 1952) and Graham & Reed (1971) indicate

that some unicellular algae are able to adapt in several hours to conditions where bicarbonate is the major form of inorganic carbon by activation of enzyme systems.

The term "bicarbonate use" means the uptake of exogenous bicarbonate ions and their assimilation as CO_2, accompanied by the production of hydroxyl ions. It is assumed that bicarbonate ions are replaced in the bathing solution by these hydroxyl ions:

$$HCO_3^- \text{ influx} \,\|\, HCO_3^- \rightarrow CO_2 \text{ (fixed photosynthetically)}$$
$$+ OH^- \,\|\, OH^- \text{ efflux}$$

Hydroxyl ion efflux was originally proposed by Steemann Nielsen (1947) to account for $CaCO_3$ incrustations which in certain circumstances developed on the adaxial leaf surface of *Potamogeton lucens*. Smith (1970) suggested that a similar mechanism led to $CaCO_3$ banding on *Chara corallina* and, using special pH electrodes, Lucas (1973) produced evidence that the alkaline bands in this species result from HCO_3^- uptake, CO_2 fixation and subsequent localised OH^- efflux.

On the basis of the relationship between the concentration of CO_2- forms in lake-water media of various levels of alkalinity, and the rate of carbon uptake by natural phytoplankton populations, Talling (1976) deduced that there was little direct use of HCO_3^- in photosynthesis by *Melosira italica* and *Asterionella formosa*, rather more by *Fragilaria crotonensis* and considerable utilization by *Ceratium hirundinella* and *Microcystis aeruginosa*. This series represented a possible population sequence in relation to seasonal pH rise, to values over 10, during spring and summer in Esthwaite Water. The ability of bicarbonate use could have important ecological consequences amongst the microalgae.

Thus there is direct and indirect evidence for bicarbonate use in photosynthesis for a limited number of macrophytes and microalgae, whilst the results of Felföldy (1962) and Talling (1976) emphasise graded responses by a series of species rather than the "either-or" situation implied by the earlier comparative work. It is well known that, in a series of lakes of increasing alkalinity, certain species of macrophyte

are confined to the lower and other species to the upper part of the alkalinity range (Iversen 1929, Moyle 1945, Spence 1967, Hellquist 1976). Accepting that other nutrients are directly or indirectly involved in these situations, the proposition is made that the species distribution of macrophytes is linked, like that of some microalgae, to the use of exogenous carbon for photosynthesis.

The first aim of this study is to assess the influence of the carbon supply on the photosynthetic rates of a number of aquatic plants exposed to uniform experimental conditions and treatments to establish the range that these plants exhibit. A comparison of the carbon utilization abilities of macrophytes and microalgae has been carried out using several types of experiments which have been designed to ascertain the dynamics of carbon dioxide and bicarbonate uptake as well as the static parameter of compensation point. In some cases the same parameter was determined by more than one technique to serve as a check. Secondly, the physical properties of the carbonate system, closed and open to the atmosphere have been examined in relation to changes in the concentration of individual carbon species during photosynthesis. Plant behavior can then be understood in the context of the carbon supply.

MATERIALS AND METHODS

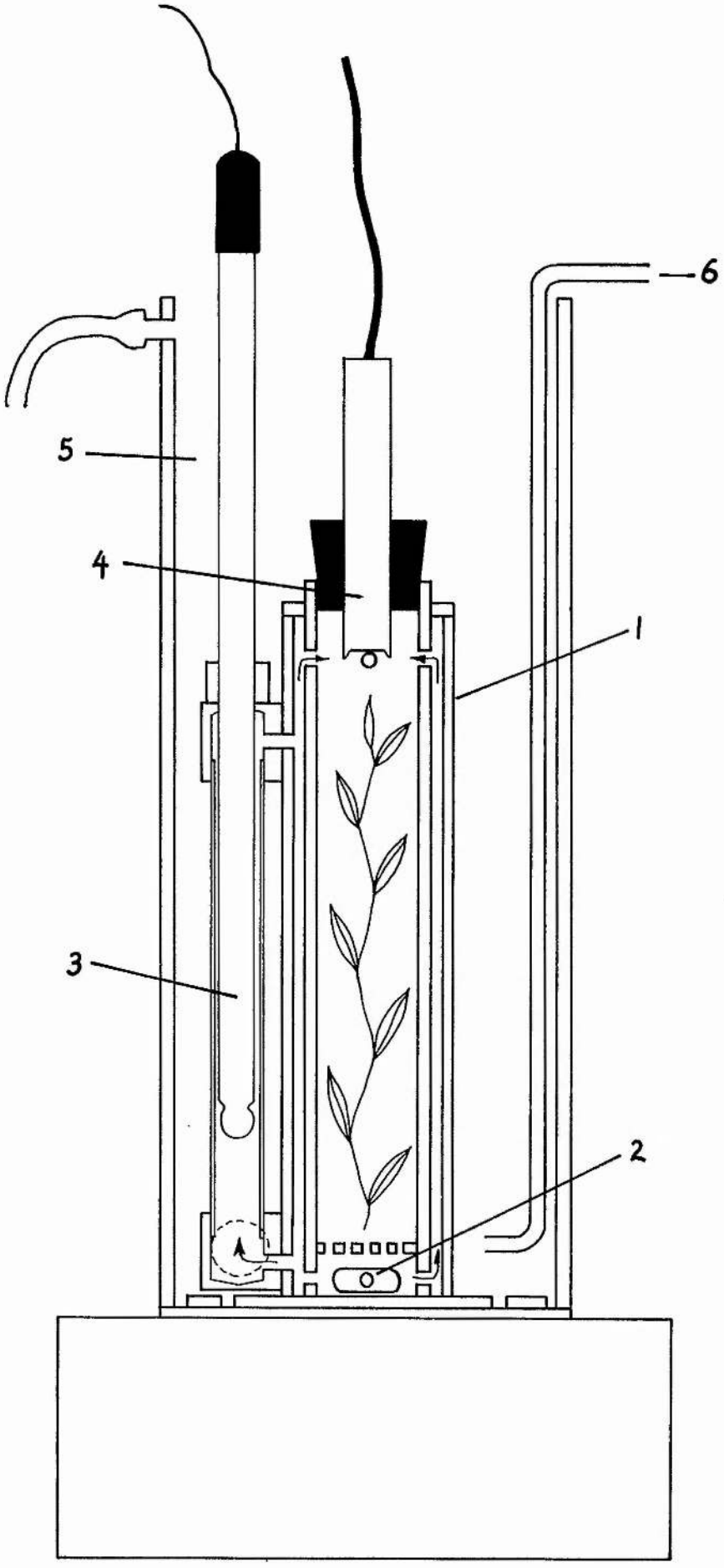
Species list.

A number of species were chosen for the study to represent a range of taxanomic groups and anatomical complexity. The source of the material used is given. Charophytes are named following Wood (1965).

Microalgae	
Anabaena cylindrica Lemmermann	Dept. of Biological Science, Dundee University.
Chlorella emersonii Shihira and Kraus.	Dundee University.
Cosmarium botrytis Meneghini	Cambridge Culture Collection
Pediastrum Boryanum (Turp) Meneghini	Cambridge Culture Collection
Mosses	
Eurhynchium rusciforme Milde	Den of Alyth, Forfar.
Fontinalis antipyretica L.	Den of Kirriemuir, Forfar.
Charophytes	
Chara vulgaris f. *contraria* .Ag. ex Kutz.	Loch Borralie, Sutherland (Borralaidh)
Nitella flexilis (Ag. ex Bruz.) Ag. *p.p.*	Loch Borralie, Sutherland
Angiosperms	
Elodea canadensis Michx.	pond, St. Andrews.
Hippuris vulgaris L.	Black Loch, Fife.
Myriophyllum alterniflorum D.C.	Loch Borralie, Sutherland
Myriophyllum spicatum L.	Loch Drumore, Angus
Potamogeton crispus L.	Loch Drumore, Angus
Potamogeton polygonifolius Pourr.	near Loch of the Lowes, Perths.
Ranunculus aquatilis L.	Loch Drumore, Angus.

FIGURE 1

Apparatus used for the measurement of oxygen concentration and pH of the bathing solution during photosynthesis by aquatic plants. 1, Plant chamber with double walls; 2, magnetic stirring bar located beneath a perforated disk; 3, side-arm connecting with inter-wall space and containing the pH electrode; 4, polarographic oxygen electrode; 5, water jacket; 6, inlet from thermostatting system. Arrows show direction of liquid flow in the plant chamber.


6
5
4
1
3
2

Measurement of photosynthesis.

The photosynthetic activity of aquatic plants immersed in various solutions was measured by continuous recording of oxygen concentration and/or of the change in pH of the bathing solution during photosynthesis from which the rate of net oxygen production or carbon uptake could be calculated. Retention of oxygen in the aerenchyma as described by Hartman & Brown (1967), frequently used as a criticism of this technique, did not prove to be a problem using the apparatus described. Plants stored in the dark to deplete their oxygen reserves showed a slight lag phase upon illumination and after a few minutes showed a very steady rate of oxygen evolution. Thereafter their response to changes in the composition of the bathing solution was almost immediate. Experiments took three forms: (1) establishment of rate-substrate (kinetic)curves in solutions of low and of high pH, (2) study of the photosynthetic rates at varied pH and constant total carbon concentration and (3) pH drift experiments at constant alkalinity.

Apparatus

All experiments were carried out in the apparatus shown in Fig. 1 which was designed to allow conditions of light and temperature to be precisely controlled while providing good circulation around the plants and the electrodes. The cuvette was constructed of two concentric perspex tubes 38 and 26 mm internal diameter respectively with a 3 mm space between them. Overall length was 190 mm giving a volume of 160 ml with the electrodes in place.

Circulation in the system was provided by a stirring bar which acted as a centrifugal pump, forcing water out through holes at the bottom of the inner tube and up through the space between the inner and outer tubes. At the top, the flow impinges on the oxygen electrode membrane which was positioned so as to be in the area of maximum current velocity. The oxygen electrode used was a Beckman Instruments 39553 O_2 Sensor connected to a Beckman Fieldlab oxygen meter. This electrode was chosen because it is small, completely submersible and has a low oxygen consumption rate which may be ignored. Circulation produced by the stirring bar was sufficient to render the photosynthetic rates independent from the stirring bar speed.

A side-arm connected with the space between the two walls held a combination pH electrode (Radiometer GK2403C) which with a length of 30 cm, was long enough to keep the upper end of the electrode out of the water in the cooling jacket. The side-arm was wrapped with aluminium foil to reduce possible effects of light on the potential of the electrode. In this model of the electrode, the calomel reference electrode is located about 1/3 of the distance up from the bulb and so will be kept at the temperature of the water jacket. Earlier versions of this electrode had the reference section at the top where it could not be thermostatted and this lead to some problems of pH drift with room temperature. The electrode was inserted through the top of the side-arm and was sealed by a sliding fit through a soft rubber sleeve. Small quantities of solutions could be injected into the cuvette without disturbance through a 'Suba Seal' closure fitted at the bottom of the side-arm. This injection point ensured that the injected solution was diluted before reaching the plant chamber and its immediate contact with the pH electrode lessened the possibility of overshooting when adjusting the pH of the bathing solution.

The whole system was thermostatted by a water jacket of perspex tubing 90 mm ID by 330 mm high supplied with water from a water bath with a refrigeration unit and heater. The water was pumped up to the jacket and returned by gravity. Illumination was provided by 3 reflector type incandescent lamps of 250 watts each, providing a total irradiance of 560 μE $m^{-2}s^{-1}$ over the wavelengths of 400 to 700 nm. This is equivalent to 120 W m^{-2} and was measured in the cuvette. All experiments were carried out at this irradiance at a temperature of 20°.

Oxygen concentration in the cuvette was recorded on a chart recorder, the rates of oxygen production being determined from the slope of the trace. With the system operating properly the trace produced should be smooth and free from 'noise'. During longer pH drift experiments, oxygen concentration and pH were recorded simultaneously at intervals by a digital recorder.

The pH electrode was connected to a Radiometer Specific Ion Meter with a recorder output providing 100 mv at full scale deflection. The digital recorder accepted up to 200 mv with a resolution of 0.1 mv enabling a pH resolution of 0.01 unit.

Calibration of the electrode, meter and recorder system was carried out using two buffers maintained at 20°. The calibration was rechecked at the end of an experiment. Drift was usually less than 0.02 unit over 8 hours.

Protocol of Experiments

A Effects of cations and anions on photosynthetic rates.

A series of experiments were carried out using *Elodea* to determine whether mixed-salt bathing solutions produced higher photosynthetic rates as described by Steemann Nielsen (1947). The plant material used was marl-free and was stored with several changes of distilled water in the light for about 18 hours. Photosynthesis initially took place in 2 mM solutions of bicarbonate supplied as the Na^+, K^+, Ca^{2+} or NH_4^+ salt. Ethanolamine bicarbonate prepared by bubbling CO_2 gas through ethanolamine was also used. After the photosynthetic rate had been established in the single cation solution, 1 ml of a mixed salt solution was injected into the cuvette to give a 2 millimolar solution of each of the missing cations. These were supplied as Na_2SO_4, KNO_3, $CaCl_2$ and $(NH_4)_2SO_4$. Ethanolamine was not used in making up the complete mixture. After the addition of the complementary cations the photosynthetic rate was again measured and compared with the single salt rate.

B Rate-substrate (kinetic) curves at low and high pH.

A series of experiments were performed on a range of species in an attempt to determine their affinities for carbon dioxide and bicarbonate, to provide a means of evaluating the use of these species in nature. Carbon dioxide in solution or potassium bicarbonate was added in increments to a bathing solution using a Radiometer Titrator ABU 1b of the piston type. After each addition the photosynthetic rate was determined from the net oxygen production rate.

Kinetic curves of CO_2 uptake were generated by adding a solution of CO_2 in distilled water prepared by bubbling CO_2 gas through water for several minutes at known temperature and pressure. The resulting solution was diluted to 0.8 of saturation with water freed of O_2 and CO_2 by purging with nitrogen gas. This dilution was made to prevent bubble formation in the titrator reservoir which would force extra CO_2 solution into the cuvette during additions. The solution was stored in a 100 ml glass syringe with no gas phase. Its strength was checked by titration with 0.2 N Na_2CO_3. The resulting CO_2 concentrations agreed closely with the value calculated from the absorption coefficient for CO_2 at the temperature and pressure at the time the solution was prepared. (See Appendix I).

Plant material was placed in distilled water and illuminated for several hours to deplete the carbon supply. Marl-free material was used as it proved difficult to deplete plants which had marl deposits. Algae were separated from the medium in which they had been grown by centrifugation followed by washing with distilled water. Equal concentrations of algae were obtained by adding equal volumes of concentrated algal suspension to the bathing solution.

The plant material was put into the cuvette with a bathing solution of distilled water purged with N_2 to lower the oxygen concentration. The pH of the water was lowered with HCl to about pH 5.5 to reduce the dissociation of CO_2. Oxygen production was measured for several minutes with no addition of CO_2 to ensure that the material had been depleted of stored CO_2 and that no oxygen was being released. Thereafter increments of CO_2-water were injected into the cuvette through a narrow gauge hypodermic needle connected to the titrator. After each addition, the oxygen production rate was measured for about 5 minutes once a steady rate of oxygen evolution had been established.

Bicarbonate curves were similarly produced. The macrophytes used in the CO_2 uptake experiments were re-used in the bicarbonate experiments after rinsing with distilled water. The bathing solution used in these experiments was deoxygenated water buffered to pH 8.8 with 5 mM Na_2HPO_4-NaOH which in the presence of bicarbonate gives an equilibrium CO_2 concentration of about 0.3% of the bicarbonate concentration. The bicarbonate concentration

was increased by adding increments of 1.5 M potassium bicarbonate from the titrator. At the end of the experiment, macrophytes were rinsed and dried for weighing. The weight of algae used was determined by drying a volume of the concentrated suspension.

C Photosynthetic response with varied pH and constant total carbon concentration.

Net oxygen production rates were measured in solutions of potassium bicarbonate containing a fixed total carbon concentration. By adding small quantities of strong HCl or KOH to this closed system, pH was altered along with the proportions of free CO_2, HCO_3^- and CO_3^{2-}.

D pH-drift at constant alkalinity.

In these experiments, carbon assimilation took place in a solution of known alkalinity prepared by dissolving potassium bicarbonate in O_2-free water. The change in pH during photosynthesis can be used to calculate carbon uptake by the plants, provided the alkalinity of the solution remains constant. A description of the pH-drift technique and a discussion of its drawbacks is given by Raven (1970) and by Talling (1976).

Calculation of the equilibrium distribution of solutes in inorganic carbon solutions.

In a solution containing dissolved inorganic carbon, the species H_2CO_3, CO_2, HCO_3^- and CO_3^{2-} are present in proportions determined by the H^+ and OH^- concentrations, the ratios giving the ionization constants;

$H_2CO_3 \rightleftharpoons CO_2 + H_2O$ pK hydration -2.8 (20°)

$CO_2 \rightleftharpoons H^+ + HCO_3^-$ pK 6.381 (20°)

$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$ pK 10.377 (20°)

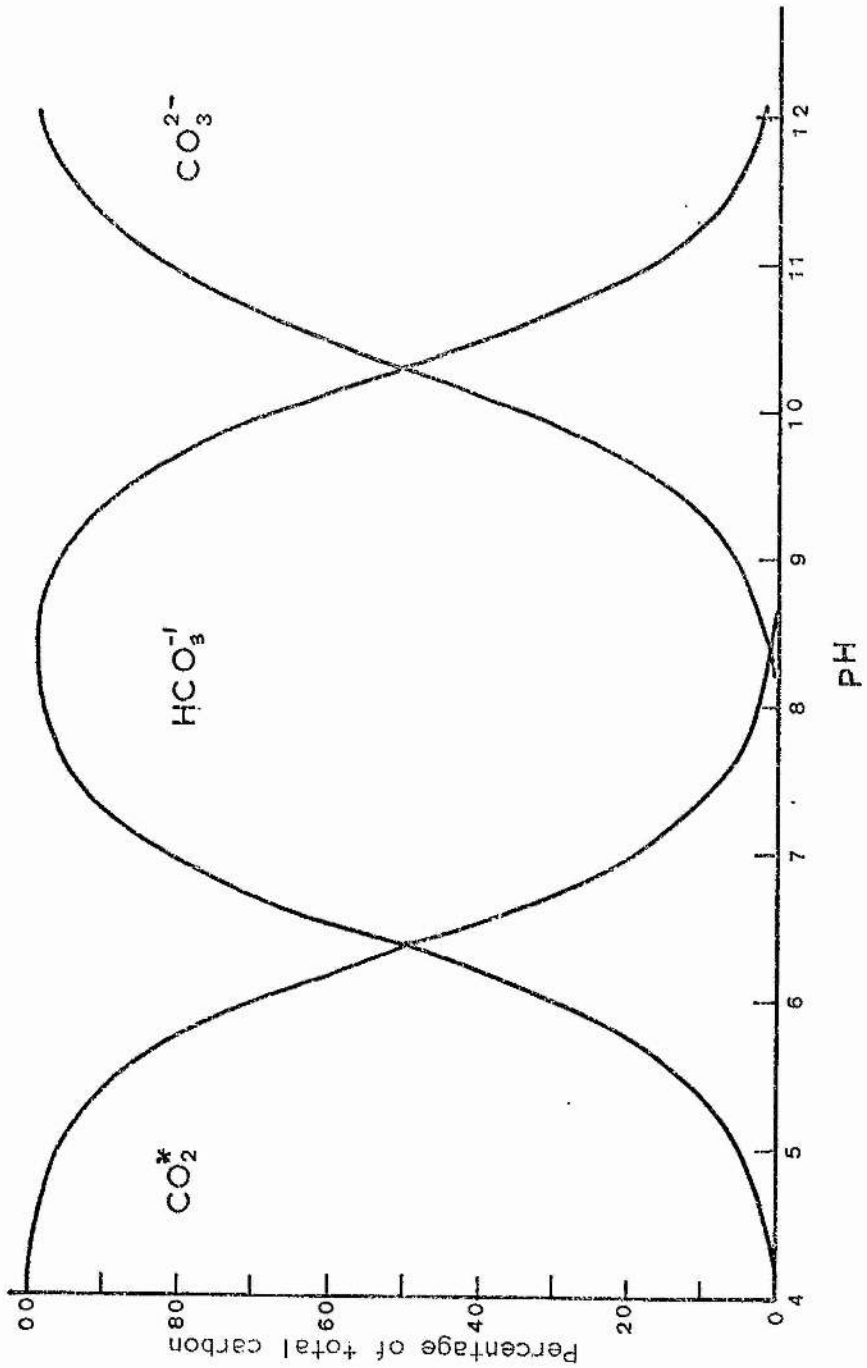
These species may be grouped to give three commonly used parameters.

$$\text{Total alkalinity (Alk)} = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] + [H^+]$$

$$\text{Total carbon } (C_T) = [CO_2^*] + [HCO_3^-] + [CO_3^{2-}]$$

FIGURE 2

Relationship between pH and the proportions of the constituents of total inorganic carbon (C_T) (free carbon dioxide, bicarbonate and carbonate). Calculated from the equations of Stumm and Morgan (1970): see text.


CO_2^*
HCO_3^{-1}
CO_3^{2-}
Percentage of total carbon
0
20
40
60
80
100
4
5
6
7
8
9
10
11
12
pH

$$\text{Free } CO_2 \ (CO_2^*) \quad = CO_2 \text{ (aqueous)} + H_2CO_3$$

As the proportion of H_2CO_3 is much smaller than $CO_{2(aq)}$ (approx 1/650) the term CO_2^* will be used to denote free CO_2 rather than the term $H_2CO_3^*$ adopted by Stumm and Morgan (1970).

In solution the solute distributions at given $[H^+]$ are given by the ionization fractions α_o for CO_2^*, α_1 for HCO_3^- and α_2 for CO_3^{2-}.

$$\alpha_o = \left(\frac{K_1'}{[H^+]} + 1 + \frac{K_1' K_2'}{[H^+]^2} \right)^{-1} = \frac{1}{\text{antilog}(pH-pK_1') + 1 + \text{antilog}(2pH-pK_1'-pK_2')} \quad (1)$$

$$\alpha_1 = \left(\frac{[H^+]}{K_1'} + 1 + \frac{K_2'}{[H^+]} \right)^{-1} = \frac{1}{\text{antilog}(pK_1'-pH) + 1 + \text{antilog}(pH-pK_2')} \quad (2)$$

$$\alpha_2 = \left(\frac{[H^+]^2}{K_1' K_2'} + 1 + \frac{[H^+]}{K_2'} \right)^{-1} = \frac{1}{\text{antilog}(pK_1'+pK_2'-2pH) + 1 + \text{antilog}(pK_2'-pH)} \quad (3)$$

The equilibrium constants used are corrected for the total ionic strength of the solution by the expressions used by Larson and Buswell (1942):

$$pK_1' = pK_1 - \frac{0.5\, I^{\frac{1}{2}}}{1 + 1.4\, I^{\frac{1}{2}}} \quad (4)$$

$$pK_2' = pK_2 - \frac{2\, I^{\frac{1}{2}}}{1 + 1.4\, I^{\frac{1}{2}}} \quad (5)$$

$I \approx 2.5 \times 10^{-5} S$ where S is the total dissolved solids in mg litre^{-1}. The absolute concentration of each species in a solution of known C_T is

$$[CO_2^*] = C_T \cdot \alpha_o$$
$$[HCO_3^-] = C_T \cdot \alpha_1$$
$$[CO_3^{2-}] = C_T \cdot \alpha_2$$

The solute proportions are shown in Fig.2 expressed on a percentage basis. If alkalinity is kept constant then C_T will vary with pH.

$$C_T = \frac{Alk - [OH^-] + [H^+]}{\alpha_1 + 2\alpha_2} \quad (6)$$

FIGURE 3

Relationship of C_T concentration to pH at 3 levels of alkalinity. The intersecting line shows the C_T concentration and pH occurring when the solution is in equilibrium with the CO_2 in the air at 20°.

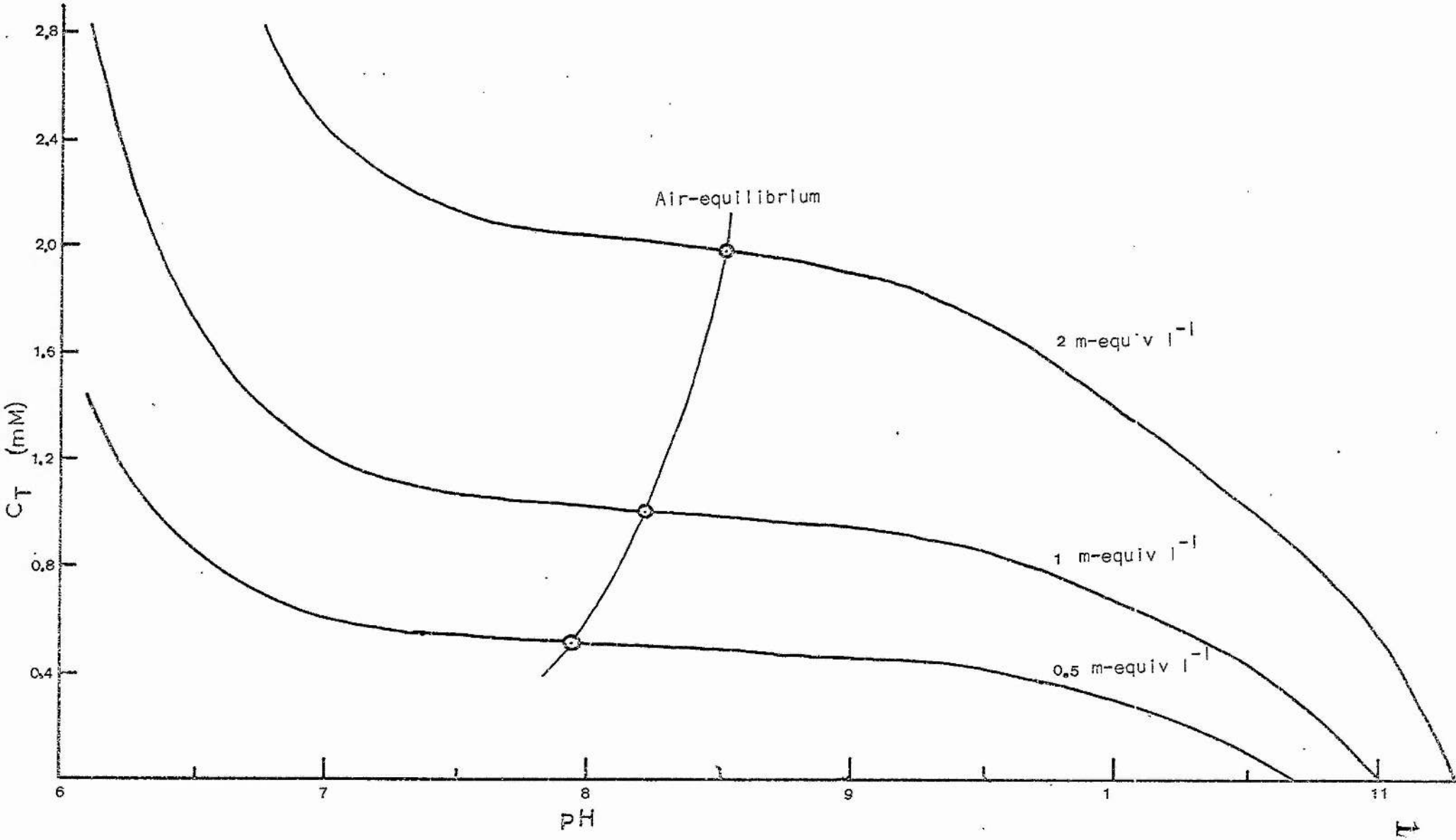
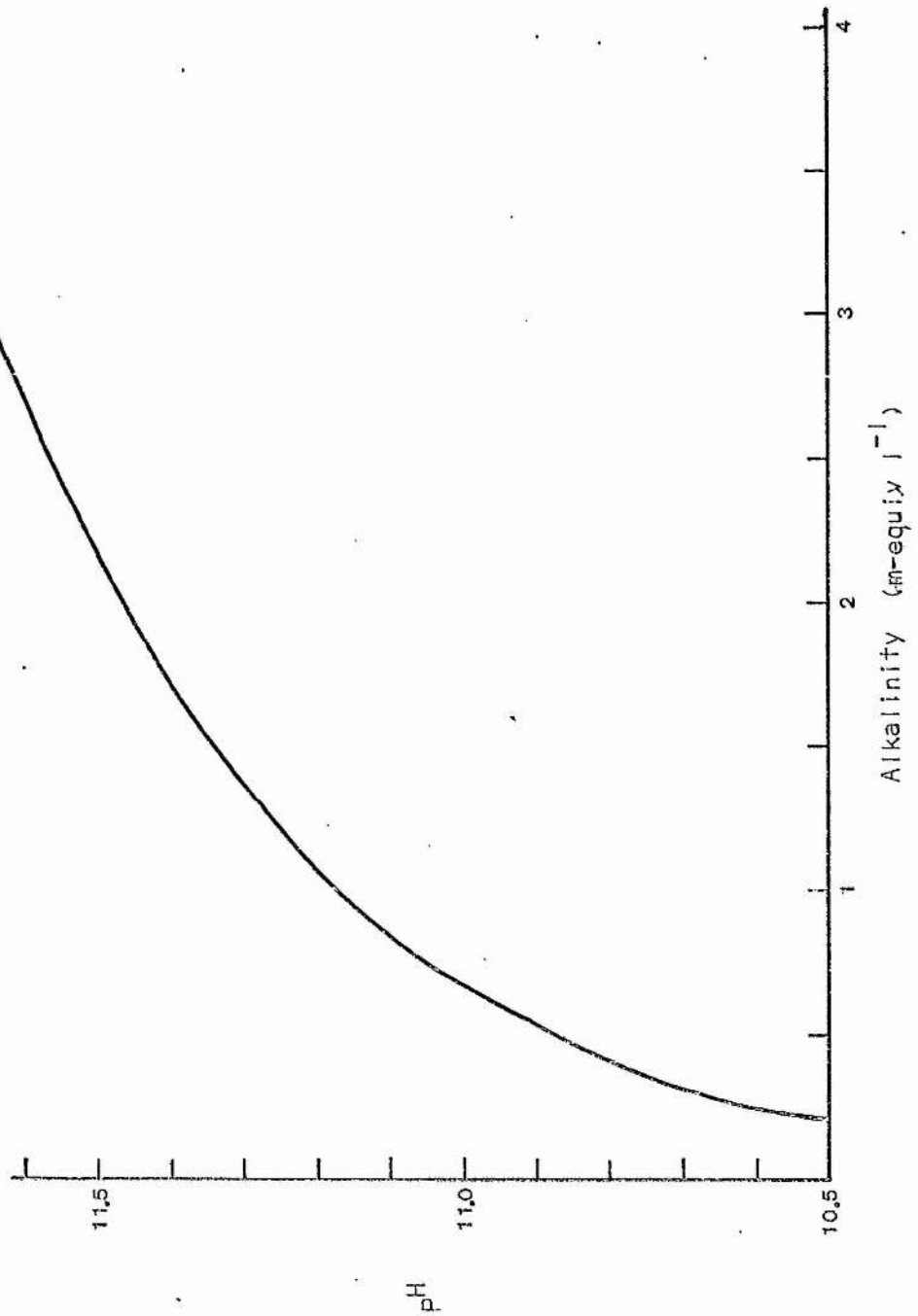

2,8
2,4
2,0
1,6
1,2
0,8
0,4
C_T (mM)
Air-equilibrium
2 m-equiv l^{-1}
1 m-equiv l^{-1}
0,5 m-equiv l^{-1}
6
7
8
9
1
11
pH

FIGURE 4

Calculated maximum pH attainable by the removal of CO_2 while maintaining a constant given alkalinity at 20° C.


pH
11,5
11,0
10,5
1
2
3
4
Alkalinity (m-equiv l^{-1})

If the carbon taken from the bathing solution during photosynthesis is obtained via the reaction:

$$HCO_3^- \rightleftharpoons \underset{\text{assimilated}}{CO_2} + OH^-$$

then the carbon is replaced by OH^-, the pH rises and the alkalinity remains constant. As a check on this reaction, the alkalinity was measured at the end of the experiments.

The species composition of a bathing solution may be obtained from the alkalinity and pH using the tables in Appendix III which were generated from equations 1-3 and 6. The pH values resulting from the removal of CO_2 from solutions of differing alkalinity are illustrated in Fig. 3, while the maximum pH which may be attained in a solution of known alkalinity by removing carbon to the point where $C_T = 0$ is given in Fig. 4. When C_T falls to zero, the original alkalinity, in the absence of other weak acid salts is represented only by OH^- and the pH is equal to $pK_w - pOH^-$, where pK_w is the ionization constant of water.

pH-drift experiments using those species which were able to use most of the available carbon were carried out in two sections, one starting at pH 7 allowing the pH to rise to about 9, then replacing the solution with another of the same alkalinity at a pH of about 9. This was done to minimize as far as possible the build-up of oxygen in the system.

Results.

A Effects of cations and anions on photosynthetic rates.

Steemann Nielsen (1947) tested the effects on photosynthetic rates of *Myriophyllum spicatum* by mixed cation solutions compared to single cation bicarbonate solutions. He found that single cation bathing solutions did not produce as high a photosynthetic rate as a bathing solution consisting of several cations. This was particularly true at pH values over 8 and that the enhancement of photosynthesis was $Ca > Na > K$.

Table I shows the photosynthetic rates of the same plant material before and after the addition of the complementary

TABLE I

Effects of cations and anions on photosynthesis.

Single cation	pH	O_2 production rate ($m\mathcal{L}^{Moles}\ h^{-1}$)	pH	O_2 production rate ($m\mathcal{L}^{Moles}\ h^{-1}$)	Rate of single cation / complete rate
NH_4^+	9.00	0.836	8.95	0.725	1.15
Na^+	8.68	1.036	8.64	0.933	1.16
K^+	8.80	0.750	8.78	0.700	1.07
Ca^{2+}	7.92	0.951	7.99	0.865	1.10
Ethanolamine	8.83	0.332	9.21	0.348	0.95

cations used to produce a complete medium. For all cations except ethanolamine, *Elodea* photosynthesisised marginally better in the single cation solutions. At no time were the effects noted by Steemann Nielsen seen. The slight decrease in the photosynthetic rate on the introduction of the other cations and anions may be due to a decrease in the activity of bicarbonate and CO_2^*. This contradiction of Steemann Nielsen's findings cannot be explained other than on the basis of methodology.

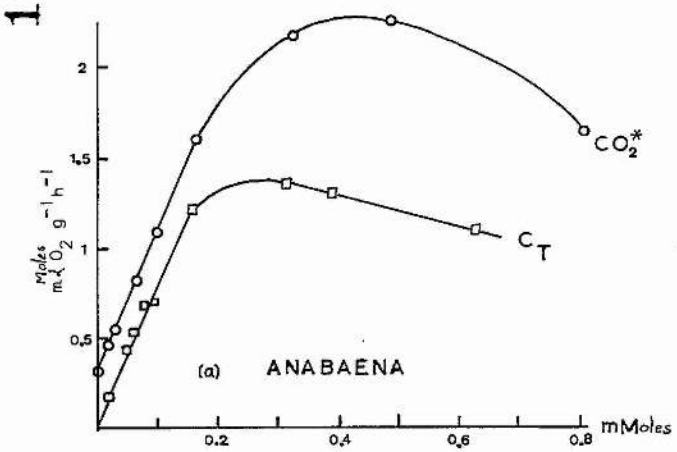
B Rate-substrate (kinetic) curves at low and high pH.

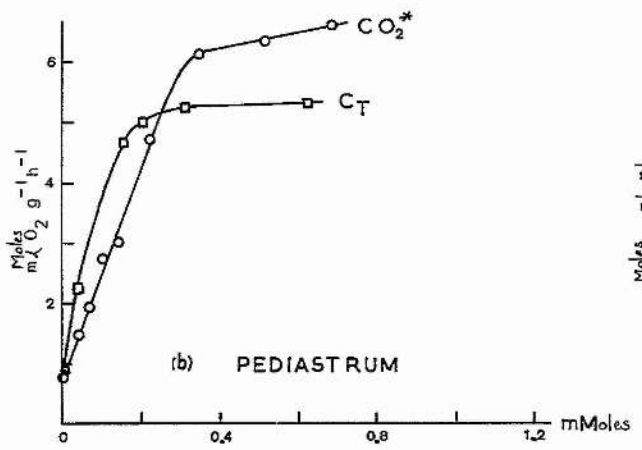
The kinetic curves for six species are given in Fig. 5 ; the kinetics of two additional species, *Eurhynchium rusciforme* and *Potamogeton crispus* are presented in the tables. The photosynthetic rates produced by increasing CO_2^* at low pH are shown in the figure for each species. Curves produced by the addition of HCO_3^- are more easily shown as a function of equilibrium CO_2 concentration which constitutes 0.3% of the bicarbonate added at pH 8.8. Because their photosynthetic rates in bicarbonate are relatively low, this type of plot can be constructed for the macrophytes. However, the photosynthetic rates of the microalgae increase very rapidly with increasing bicarbonate concentration. This precludes plotting the equilibrium CO_2 curves on the same abscissa as the curves obtained in CO_2^* since the slope of the plot is too great. For microalgae in bicarbonate solutions, therefore, photosynthetic rate is plotted as a function of total inorganic carbon (C_T) concentration.

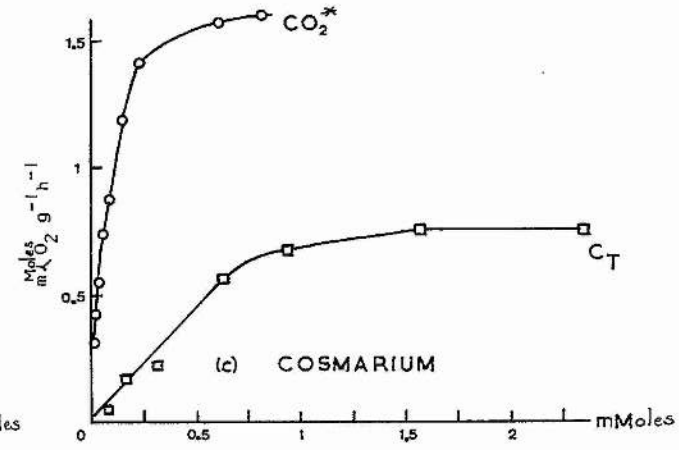
The saturation net photosynthetic rate (V_{max}) and the substrate concentration yielding $\frac{1}{2}$ V_{max} (K_m) in CO_2^* and HCO_3^- solutions were estimated by fitting the experimentally produced curves to rectangular hyperbolae using the linear transformation of Pasciak & Gavis (1975) following Dowd & Riggs (1965), in which the substrate concentration divided by the net photosynthetic rate is plotted on the ordinate against substrate concentration on the abscissa. The slope of the line is equal to $1/V_{max}$ and the plot intercepts the negative abscissa at $-K_m$. This transform is more suitable than the Lineweaver-Burk plot because it puts more emphasis on points at higher substrate concentrations where the effects of transport limitation are smaller. The values of V_{max} and K_m

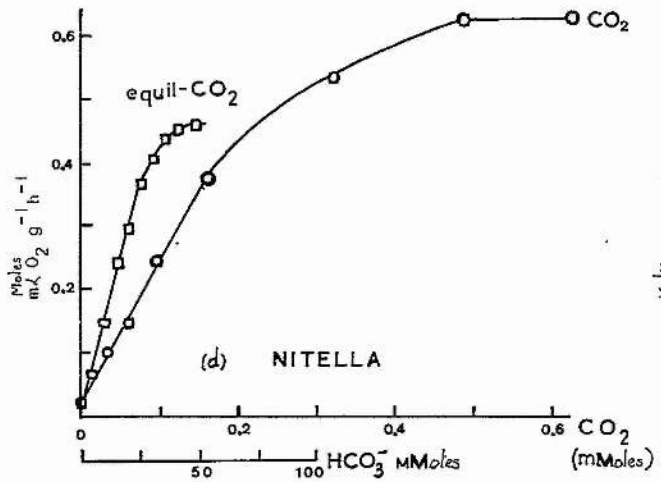
FIGURE 5

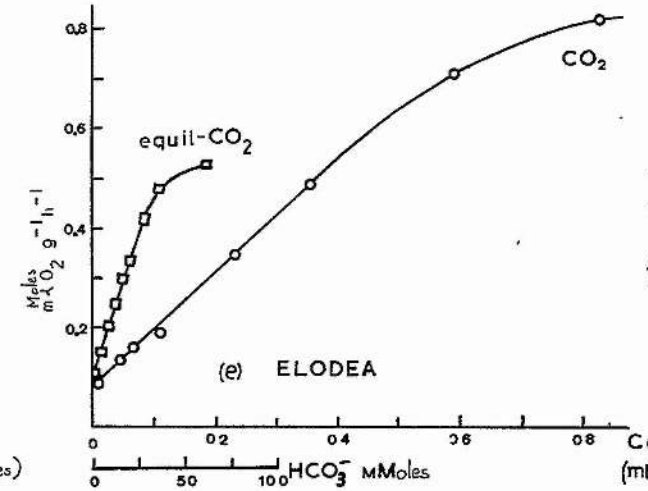
Rate-substrate (kinetic curves. Graphs (a) to (c) show net oxygen production rates as a function of total carbon concentration (C_T) at pH 8.8 and of free CO_2 (CO_2^*) concentration at pH around 5.5. Graphs (d) and (e) show net oxygen production as a function of equilibrium CO_2 concentration at pH 8.8 and of CO_2^* concentration at pH 5.5. Curve (f) shows oxygen production rates at pH 9.45 and in CO_2 near pH 5.5.

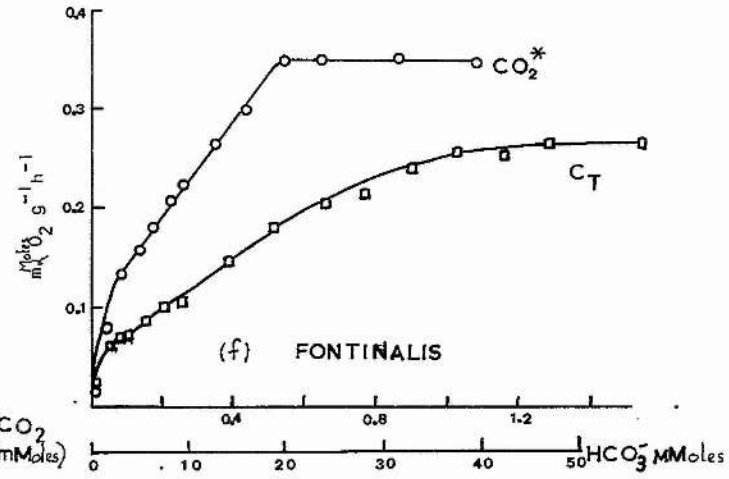

(a) ANABAENA
CO_2^*
C_T
mMoles


(b) PEDIASTRUM
CO_2^*
C_T
mMoles


(c) COSMARIUM
CO_2^*
C_T
mMoles


(d) NITELLA
equil-CO_2
CO_2
HCO_3^- mMoles
CO_2 (mMoles)


(e) ELODEA
equil-CO_2
CO_2
HCO_3^- mMoles
CO_2 (mMoles)


(f) FONTINALIS
CO_2^*
C_T
HCO_3^- mMoles

for a range of species is given in Table 2 . Saturating concentrations of CO_2^* and C_T were taken directly from the curves and are given in Table . 3.

Saturation concentrations for CO_2^* have a five-fold range (from 0.3 to 1.5 mM) compared with a more than 200-fold range in saturating C_T concentrations (0.15 to 37 mM). This range in C_T concentrations represents the difference between the response of *Anabaena* or *Pediastrum* and that of *Elodea* or *Fontinalis*. Allowing for variations in temperature, irradiance and spectral quality the concentrations of bicarbonate, pH, and of other ions in the bathing solutions used, the present results are generally comparable with those of other authors given in Table 3.

The present value for CO_2^* saturation is, however, rather higher than Fogg & Than Tun's (1961) value, obtained in carbon incorporation experiments lasting several days. They showed that carbon assimilation (expressed as mg C (mg N)$^{-1}$ day^{-1}) of *Anabaena cylindrica* reached its optimum at 20° when the pCO_2 in the overlying gas phase was 0.2% which is equivalent to 78 μM CO_2^* in the water. Saturating concentrations of CO_2^* occurred at a pCO_2 of 0.25% (97 μM) which is of the same order as that reported by other workers as saturating for photosynthesis of simple algae (Rabinowitch 1956, p. 893) but such figures have been criticised by Steemann Nielsen & Jensen (1958) as being too high. However both Fogg & Than Tun and Steemann Nielsen ignore the bicarbonate component of the carbon supply so their saturating CO_2 concentrations may all be too low. Fogg & Than Tun used Allen and Arnon's medium which they reported had a pH of 7.4 when in equilibrium with a pCO_2 giving a CO_2^* concentration of 97 μM. At this pH only 7.6% of the total carbon will be in the form of CO_2^* , thus C_T in their bathing solution was about 1.3 mM.

The free CO_2 kinetics for *Fontinalis* are in good agreement with those published by Steemann Nielsen (1947) and Harder (1921). Steemann Nielsen's C_T curve at pH 8.3 is similar to the C_T curve shown in Fig. 5.done at pH 9.45. The *Fontinalis* curve was produced at this pH to reduce the equilibrium CO_2 contribution which would become very large at the high C_T concentrations required to saturate the photosynthetic rate. Steemann Nielsen applied

TABLE 2

V_{max} and K_m for CO_2 at low pH and for C_T at pH 8.8*

Constants are derived from the Dowd & Riggs (1965) linear transform of the kinetic

Species	CO_2^*		C_T	
	V_{max} (Moles mO_2 $g^{-1}h^{-1}$)	K_m (μM)	V_{max} (Moles mO_2 $g^{-1}h^{-1}$)	K_m (μM)
Anabaena cylindrica	2.11	64	1.42	50
Pediastrum Boryanum	7.39	38	5.22	10
Cosmarium botrytis	2.11	172	0.87	400
Nitella flexilis	0.64	100	0.60	8,100
Eurhynchium rusciforme	0.46	81	0.52	8,000
Fontinalis antipyretica	0.35	170	0.31	11,000
Elodea canadensis	1.06	300	0.99	16,300
Potamogeton crispus	0.80	200	0.77	23,400

* pH of 9.45 used for *Fontinalis*.

TABLE 3

Saturating concentrations for C_T(mM) and for CO_2^*(mM) in the bulk solution.

The third column indicates the pH value in 10 mM C_T where the free CO_2 concentration drops below the saturating CO_2 concentration.

Species	C_T (mM)	CO_2^* (mM)	pH in 10 mM C_T solution
Anabaena cylindrica	0.15	0.01[1]	
		0.30	7.8
Pediastrum Boryanum	0.16	0.40	
Cosmarium botrytis	1.60	0.75	
Chara corallina	1.50	1.50[2]	
Myriophyllum spicatum	10.0[3]	0.50[3]	
Nitella flexilis	18.0	0.7	7.45
Elodea canadensis	20.0	0.8	7.38
Eurhynchium rusciforme	20.0	0.7	7.45
Fontinalis antipyretica	30[4]	0.6[4]	
	32[5]	0.7[5]	7.45
	37	0.55	
Potamogeton crispus	-	1.5	
Potamogeton praelongus	-	0.8[6]	

1. Fogg and Than Tun, 1960
2. Lucas 1975: Fig.4, p. 337
3. Steemann Nielsen, 1947: Fig. 5 p.17 (50,000 lux)
4. *Ibid.*, Fig. 6, p.18, (15,000 lux)
5. Harder, 1921, 18,000 lux
6. Black, 1973

corrections for equilibrium CO_2 to his pH 8.3 curve and concluded that nearly all of the photosynthetic rate could be accounted for on the basis of CO_2 uptake alone. He claimed that at pH 9.5, it required 18 mM C_T to give any oxygen evolution. In this study, a measurable photosynthetic rate occurred in 4 mM C_T at pH 9.45, a concentration which was further confirmed by the pH drift experiments.

The apparent K_m for C_T at pH 8.8 is assumed to be a measure of affinity for bicarbonate while the ratio of $K_{m(C_T)}/K_{m(CO_2)}$ is a relative measure of the degree of preference for CO_2^*. Thus a low ratio would indicate a stronger affinity for bicarbonate while a ratio greater than 1 would indicate a preference for CO_2. (Table 4). Assuming that the concentration of CO_2^* at air-equilibrium is important to a species in a solution at pH 8.8 even though it is only 1/300 of the bicarbonate concentration, this equilibrium CO_2 would increase the error resulting from equating apparent K_m for C_T with that of bicarbonate. It would slightly decrease the $K_{m(C_T)}/K_m\ (CO_2)$ ratio. This error is unlikely to be significant at least in the case of those species which have a low ratio, that is, similar affinities for CO_2 and bicarbonate.

In Table 4, the macrophytes all show a distinctly greater affinity for CO_2^* than for bicarbonate, while of the microalgae, *Cosmarium* shows a much smaller preference for CO_2^*, and *Anabaena* and *Pediastrum* appear to have about the same affinity for CO_2^* and HCO_3^-.

A further comparison can be made between the concentration of CO_2^* and C_T or HCO_3^- needed to produce the same rate of net oxygen evolution. The first column of Table 5 compares the C_T concentration at pH 8.8 with the concentration of CO_2^* at low pH yielding the same photosynthetic rate, each value being derived from five points on the kinetic curves. Subtraction of the photosynthetic rate contributed to the overall rate by equilibrium CO_2 leaves the rate produced by HCO_3^- only. The second column of Table 5 gives the $[HCO_3^-]$ to $[CO_2^*]$ ratio yielding the same photosynthetic rate. A comparison of both columns shows that the equilibrium CO_2 is not important enough to affect the ranking of the species. Relative to the K_m ratios of Table 2 however, the ranking of macrophytes apart from *Elodea* is quite different. This might result from, *inter alia*, differing diffusive resistances to CO_2.

TABLE 4

Ratios of $K_{m(C_T)}$ to $K_{m(CO_2^*)}$

(Data derived from Table 2)

Species	$\frac{K_{m(C_T)}}{K_{m(CO_2^*)}}$
Pediastrum Boryanum	0.3
Anabaena cylindrica	0.8
Cosmarium botrytis	2.3
Nitella flexilis	81.
Elodea canadensis	54.
Fontinalis antipyretica	65.
Eurhynchium rusciforme	98
Potamogeton crispus	117

TABLE 5

Ratios of $[C_T]$ or $[HCO_3^-]$ at pH 8.8 to $[CO_2^*]$ producing the same rate of net photosynthesis

Standard error is given for each species. Data are derived from the kinetic curves of Fig. 5 and the unillustrated curves for *Eurhynchium rusciforme* and *Potamogeton crispus*.

Species	$\frac{[C_T]}{[CO_2^*]}$	$\frac{[HCO_3^-]}{[CO_2^*]}$
Pediastrum Boryanum	0.4 ± 0.09	0.04
Anabaena cylindrica	0.7 ± 0.01	0.7
Cosmarium botrytis	15 ± 1.1	18
Elodea canadensis	37 ± 1.3	52
Potamogeton crispus	51 ± 1.24	66
Eurhynchium rusciforme	62 ± 2.25	81
Nitella flexilis	72 ± 1.63	101
Fontinalis antipyretica	-	132

Diffusion limitations on photosynthetic rates.

Interpretation of the kinetic curves produced by the rate-substrate experiments often proved to be difficult. The curves did not always take the form of rectangular hyperbolae produced by enzyme mediated reactions. This caused difficulty in determining values for K_m and V_{max}. The distortion occurred at low substrate concentrations where the curve was too straight and was most noticeable in the macrophyte curves. The kinetic curves for the microalgae closely followed the hyperbolic form. This straightening of the curve appeared to be related to the complexity of the photosynthetic organ involved and thus to the overall path length from the bulk solution to the site of consumption. Similar curves were produced by Blackman & Smith (1911) in their classic study on carbon uptake by aquatic plants.

The rate of diffusion of carbon dioxide in water is about 10^4 times slower than it is in air. When turbulent motion and convection in the bulk solution are low, diffusion rates within the subliminar layer and the cell walls may limit photosynthetic rates of the plant under conditions where the potential demand for carbon is high.

The flux of carbon into the cells depends upon the surface area of the cell and the concentration gradient between the bulk solution and the cell surface and is described by

$$J = AD\ (C - C_R) \qquad (7)$$

where J is the flux rate; A, the area; D, the diffusion coefficient; C, the concentration in the bulk solution and C_R, the concentration at the site of consumption.

In the absence of transport limitation, the carbon uptake rate should approach the kinetics of an enzyme system described by the Michaelis-Menten relationship:

$$V_C = \frac{V_{max} \cdot C}{K_m + C} \qquad (8)$$

where V_C is the rate of uptake.

Under conditions of transport limitation such as occur at low substrate concentrations, the uptake rate achieved

(V_E) is smaller than the predicted value (V_C) because of the lowering of the concentration at the cell surface to a new value (C_R). This experimentally determined uptake rate would be

$$V_E = \frac{V_{max} \cdot C_R}{K_m + C_R} \qquad (9)$$

The value of C_R can be as low as the compensation point. A comparison of the achieved rate of net photosynthesis with the idealized rate based on V_{max} and K_m is thus a measure of the total diffusion resistance. These V_E/V_C ratios are given for eight species in Table 6 . They are derived from several points in the non-saturating part of each kinetic curve near K_m.

Hill & Whittingham (1957) have shown that under conditions of severe transport limitation, the rate-substrate curve changes from a rectangular hyperbola (Fig. 6 a) into two straight lines (Fig. 6 b). The uptake rate at non-saturating substrate concentrations is described by

$$V \text{ (net assimilation)} = \frac{K}{L} C \qquad (10)$$

where K is the diffusion coefficient ($cm^2\ s^{-1}$), L is the diffusion path length (cm) and C is the substrate concentration (moles cm^{-3}). At high substrate concentrations the system saturates, V becomes independent of the substrate concentration and $V = V_{max}$.

In cases of less severe limitation, some distortion of the rectangular hyperbola occurs at lower concentrations of substrate and only at higher levels does the curve follow the form of a rectangular hyperbola (Fig. 6c).

Equation (10) can be rearranged to give L. Normally for these purposes net assimilation is expressed in terms of rate per unit of cell surface. Results are available in the present study on the basis of plant dry weight alone, so L cannot be expressed as a length dimension. The calculated value L' given in Table 6 is only a relative index of transport limitation of CO_2 and is affected by the ratio of photosynthetic tissue to non-photosynthetic structural tissue. The microalgae show less transport limitation than the macrophytes and *Eurhynchium* and *Nitella* much less than the angiosperms which have a more complex anatomy.

TABLE 6

Comparison of the experimentally produced uptake rates (V_E) for CO_2^* and C_T with the calculated uptake rate (V_C).

	CO_2^*	C_T	CO_2^*
	$\frac{V_E}{V_C}$	$\frac{V_E}{V_C}$	$L' \times 10^{-5}$
Anabaena cylindrica	1.00	1.00	0.54
Pediastrum boryanum	0.76	-	0.27
Cosmarium botrytis	1.00	0.69	1.31
Nitella opaca	0.80	0.86	2.25
Fontinalis antipyretica	0.52	0.75	8.30
Eurhynchium rusciforme	0.57	1.00	2.40
Elodea candensis	0.74	1.00	4.80
Potamogeton crispus	0.68	0.96	5.50

V_C values are taken from idealised kinetic curves which are drawn from calculated values of V_{max} and K_m (Table 2). The factor L' indicating the relative diffusion path for CO_2^* is given by:

$$L' \ (g\ cm^{-1}) = \frac{K}{V} \cdot C$$

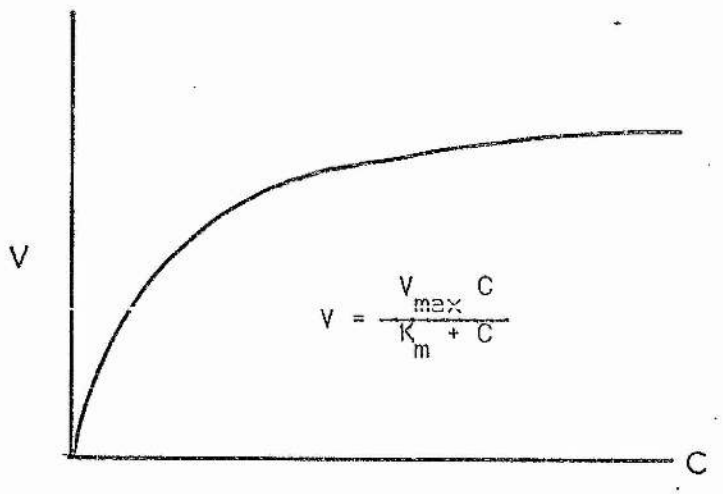
where K = diffusion ~~rate~~ constant for CO_2^* in water ($1.5 \times 10^{-5}\ cm^2\ s^{-1}$)

V = net O_2 production rate (m Moles $O_2\ g^{-1}\ s^{-1}$)

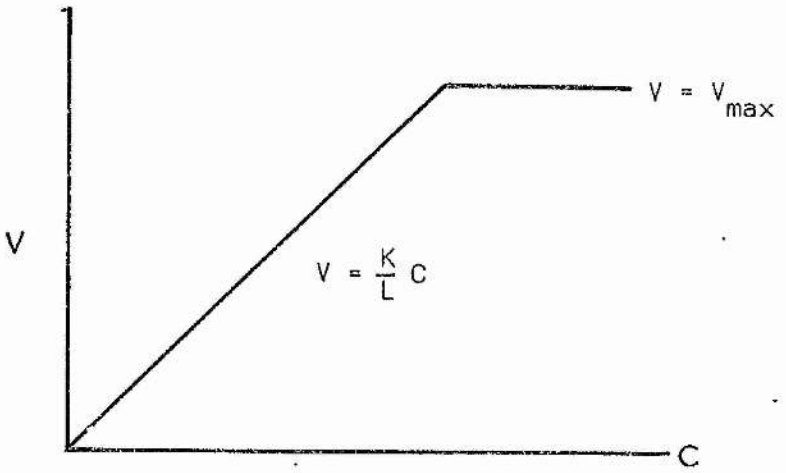
C = concentration of CO_2^* (millimoles cm^{-3})

FIGURE 6

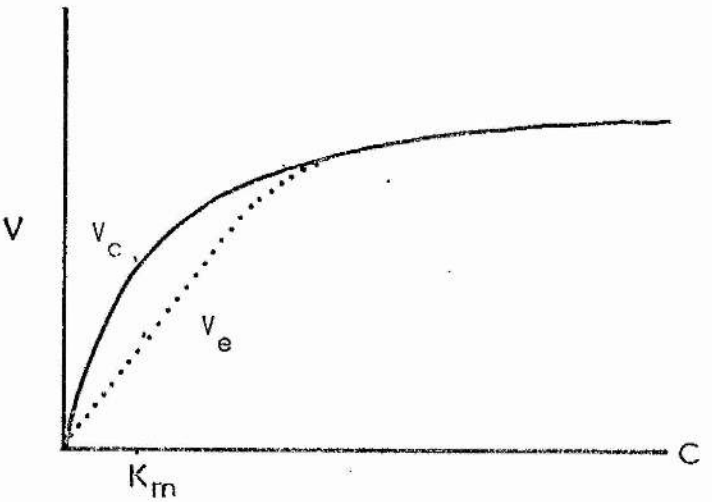
Graphs illustrating how diffusion resistance modifies the relationship between the rate of reaction, V, and the substrate concentration, C; (A) no diffusion resistance; (B) severe diffusion resistance and (C) a moderate resistance showing the depression of the rate of reaction as measured, (V_E), in relation to the corresponding point (V_C) on the ideal curve at the half-rate concentration (K_m).



(A)



(B)



(C)

The V_E/V_C ratios are a better parameter for demonstrating diffusion resistance. Values approaching unity in the microalgae reflect their simple anatomy and short diffusion paths. In the macrophytes, the affinity for HCO_3^- is generally much less than the affinity for CO_2^*. As a result, when such a plant is presented with equal concentrations, the uptake rate in bicarbonate will be much slower and from Equation (7) , the value of the term $C-C_R$ will be smaller than for CO_2^* uptake. Consequently the assimilation rate follows the Michaelis-Menten relationship more closely and the V_E/V_C ratios will approach unity. (Table 6).

The construction of kinetic curves as a method of determining apparent CO_2 and HCO_3^- affinities becomes less accurate with increasing complexity of the photosynthetic organs and increasing path length to the site of consumption. The curves become increasingly distorted and the values of apparent K_m increase and show a poorer relationship to the true K_m of the enzyme systems involved. The K_m values determined here are for intact plant shoots in a well stirred system. Those species with very tightly packed leaves like *Fontinalis* will have larger unstirred areas around the leaves and will require a higher CO_2^* concentration or rapid water flow over the leaves to achieve $\frac{1}{2}V_{max}$. At depth in lakes and in the absence currents, the apparent K_m may be much larger than reported here. Under such conditions, widely spaced, finely divided or anatomically simple leaves are an advantage.

A further weakness of this type of experiment may arise from changes in K_m for CO_2 with pH, so that the values reported here, obtained at low pH may be quite different in the presence of bicarbonate at higher pH. From data derived from the constant C_T - varied pH experiments described next, the K_m for CO_2 does not seem to change significantly up to pH 7.5 in *Elodea*, *Fontinalis* and *Eurhynchium*.

C Photosynthetic response to varied pH and constant total carbon concentration.

Aquatic plants occur in bathing solutions of widely varying pH brought about by differences in carbonate alkalinity, additions of acids or alkalies (peaty inflows, mine drainage or industrial waste) and biologically, through decomposition processes in the sediments and the photosynthetic activities of the plants themselves. The addition of acid or base to a closed system containing dissolved inorganic carbon will alter the alkalinity and shift the proportions of the carbon species present without altering their sum (C_T). If a plant has differing affinities for CO_2^* and HCO_3^- then its photosynthetic rate will respond to changes in the pH of the bathing solution. The rate may also change due to any other physiological effects that a change in external pH might have.

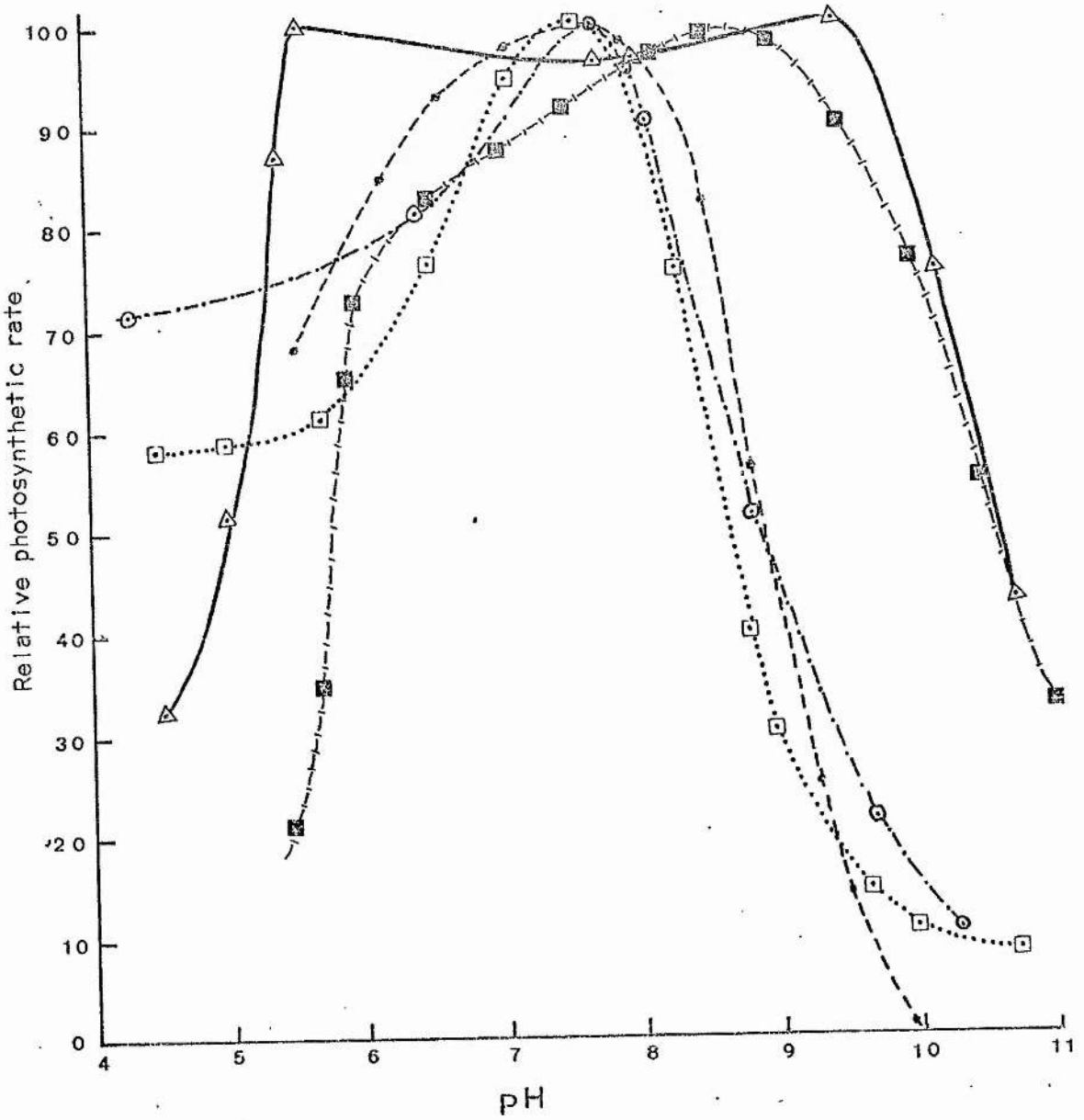
In one series of experiments, the pH of the bulk solution was varied from about 4.3 to 11 in a constant total carbon concentration of 10 mM. Fig. 7 shows the effects on the photosynthetic rate for five species expressed as a percentage of their maximum rate. All the species except *Anabaena* and *Chlorella* reached their maximum rates around pH 7.5 while the two microalgae began to decline at pH 9.4 and 8.8 respectively. A similar response with *Anabaena flos-aquae* was noted by Keenan (1973). When the macrophytes of Fig. 7 are operating at less than 20% of their maximal rates, *Anabaena* and *Chlorella* are still photosynthesising near their maximum.

The photosynthetic rate of *Elodea* and *Fontinalis*, species generally regarded as a user and a non-user of bicarbonate respectively, declined in a similar fashion as pH was raised and only above pH 9.4 did these species begin to behave differently.

The possible extent of bicarbonate use by *Elodea* was examined by repeating the experiment at lower C_T concentrations of 0.16 and 1.64 mM. Data discussed here are interpolated from Fig. 8. With an air-equilibrium concentration of 14 μM free CO_2 and a C_T concentration of 0.16 mM, the rate of net oxygen production by *Elodea* at pH 8.3 is 12% of its maximum rate at pH 6.8. This same CO_2^* concentration of 14 μM is reached at pH 8.9 in a

FIGURE 7

Photosynthesis expressed as a percentage of the maximum net oxygen production rate for *Anabaena* (—△—) . *Chlorella* (-ı-ı-□-ı-ı-) *Eurhynchium* (·—·-⊙-·—·—) *Fontinalis* (—·—·—·—·—) and *Elodea* (·····□·····); as a function of pH at a constant total carbon concentration of 10 mM.


Relative photosynthetic rate
100
90
80
70
60
50
40
30
20
10
0
4
5
6
7
8
9
10
11
pH

solution containing 1.64 mM C_T. The net photosynthetic rate of *Elodea* is now greater than it was in the 14 μM CO_2^* and 0.16 mM C_T solution but it is still only 14% of the maximum rate. Overall therefore, a ten-fold rise in bicarbonate concentration has only increased net photosynthesis in *Elodea* by about 2% of its maximum rate in the weaker solution. This implies that bicarbonate is being utilized at pH 8.9 when in a solution of 1.64 mM C_T, but to a very slight extent.

Causes of the decline in the rate of photosynthesis with increasing pH at constant C_T.

Intrest in the curves of relative photosynthetic rate at constant C_T and varied pH lies in (1) the cause of the difference between the two microalgae and the macrophytes tested, (2) causes of the fall in rate with increasing pH, (3) implications for use and non-use of bicarbonate, (4) their use as a check on the validity of the saturating CO_2^* concentrations from the kinetic experiments and (5) their ecological implications.

Comparing Table 3 and Fig. 5 it is evident that all the macrophytes examined are bicarbonate limited in 10 mM HCO_3^- so their rates of photosynthesis can be expected to decline independently from bicarbonate concentration well before the bicarbonate concentration itself begins to fall around pH 8.3. *Anabaena* has a low saturating C_T concentration which at 0.15 mM, is amply exceeded throughout the upper pH range of Fig 7 . The disparity in this species between the calculated pH of 7.8 which provides saturating free CO_2 concentrations in 10 mM C_T solutions (Table 3) and the observed pH of 9.4 above which its net photosynthetic rate declined may be explained in terms of bicarbonate use. At pH 9.4 about 85% of the carbon is present as bicarbonate which is still well above saturation. In this region pH itself may cause the decrease in the photosynthetic rate.

Table 3 gives the saturating concentrations of CO_2^* taken from the kinetic curves along with the calculated pH values in 10 mM C_T solutions above which the CO_2^* concentration drops below the saturating level. For the macrophytes of Fig. 7 , the calculated pH values for the point of inflection based on CO_2 saturation are:

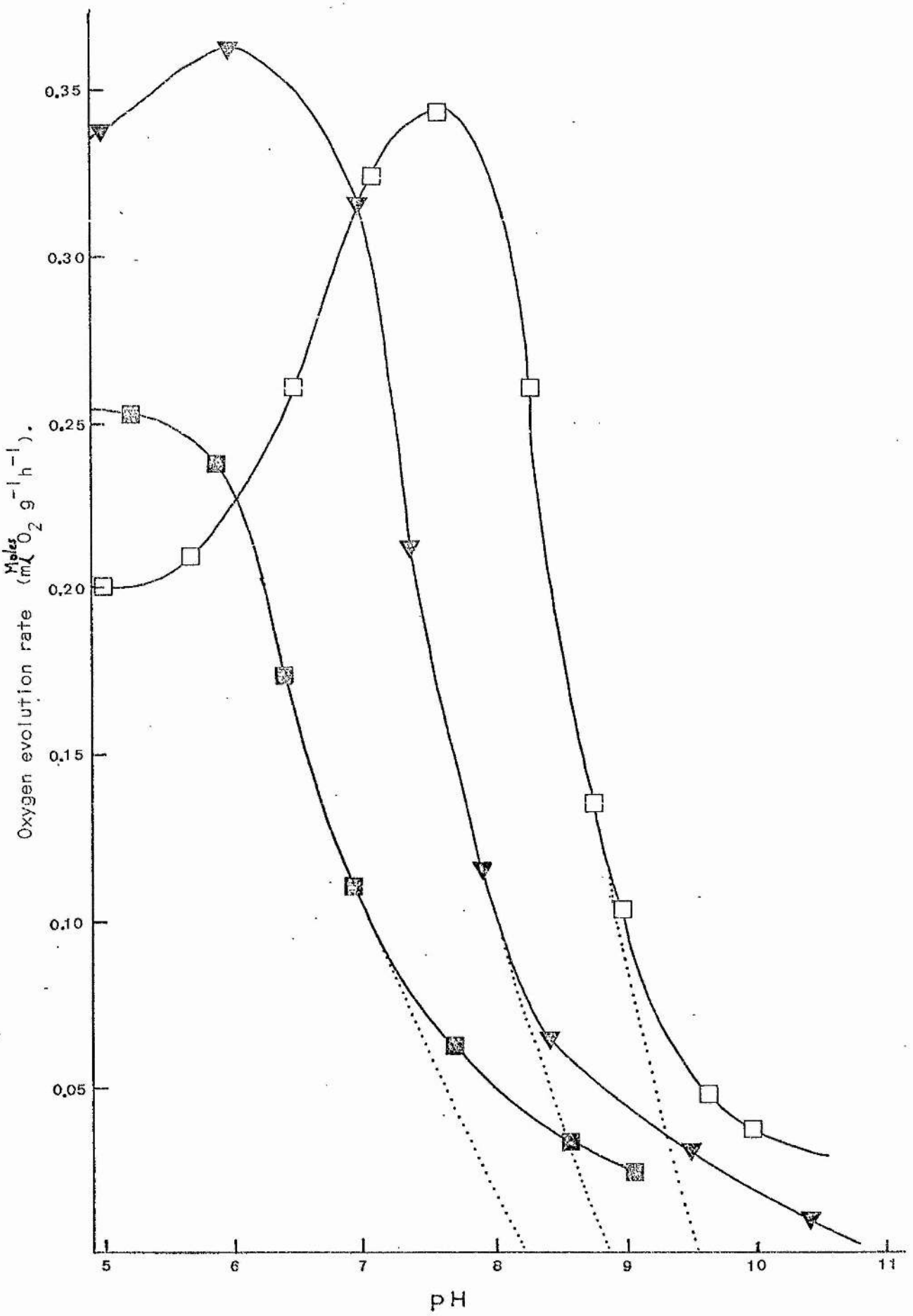
Eurhynchium pH 7.45, *Elodea* pH 7.47 and *Fontinalis* pH 7.48 and these agree within about 0.1 pH unit with the experimentally produced inflection points. This provides an independent check on the measured saturating CO_2^* concentrations.

Figure 8 shows the effect of C_T concentration on the varied pH curves of *Elodea*. As the total carbon concentration is increased, the pH at which the photosynthetic rate begins to decline also increases. The photosynthetic rate continues to fall with CO_2^* concentration and would eventually reach zero at the CO_2^* compensation point. The curves of Fig. 8 are extrapolated as shown by the dotted lines to the CO_2^* compensation point obtained from the pH drift experiments. The rate, however, does not fall as rapidly as predicted because of bicarbonate use.

Lucas (1975) carried out a similar type of experiment on *Chara corallina* involving $^{14}CO_2$ and $H^{14}CO_3^-$ uptake in a constant total carbon - varied pH system in which a series of three buffers (5 mM 2-(N-morpholino)ethanesulfonic acid (MES) and N-tris (hydroxymethyl)methylglycine (TES) and HCO_3^-/ CO_3^{2-} were used to generate and maintain set pH levels during the experiment. Lucas claimed that the saturating bicarbonate concentration for this species is 1.5 mM (obtained from a kinetic experiment). In 3 mM bicarbonate the plant should have remained bicarbonate-saturated until the pH was raised to 10.33. However when this pH was reached the photosynthetic rate had dropped to 20% of the maximum rate. Lucas explained this decrease as CO_3^{2-} inhibition of HCO_3^- uptake above pH 9.5. The drop in photosynthetic rate actually began at pH 7.2 (Lucas Fig. 6_A) in good agreement with the results of the present study and may be interpreted as the result of the CO_2^* concentration falling below saturation (at about 300 μM). Uptake of bicarbonate should have prevented the rate from falling so rapidly above pH 7.2. His saturating HCO_3^- concentration must be too low and his saturating CO_2^* concentration of 1 to 1.4 mM must be too high. It is not necessary to invoke the hypothesis of carbonate inhibition. Lucas' methodology did not describe any stirring system and the kinetic curves show the straightening characteristic of diffusion limitation. If the system were poorly stirred this would have the effect of increasing the CO_2^* saturation concentration.

FIGURE 8

Net oxygen production rate of *Elodea* as a function of pH in solutions with constant total carbon concentrations of 0.16 mMoles/ml (—■—); 1.64 mMoles/ml (—▼—); and 9.83 mMoles (—□—). Dotted lines are extrapolations to the pH yielding the free CO_2 compensation point.


0.35
0.30
0.25
0.20
0.15
0.10
0.05
Oxygen evolution rate (m Moles O_2 g^{-1} h^{-1}).
5
6
7
8
9
10
11
pH

The constant C_T-varied pH experiments can provide a means of assessing relative plant performance in mixed communities where the pH is changing due to photosynthetic activity or other causes. As pH rises, those species which have a low ability to use bicarbonate will suffer a more drastic reduction in their photosynthetic rate than those species which are more tolerant to the conditions produced by high pH.

D Results of pH - drift experiments at constant alkalinity.

As described in Section D of the Protocol, the removal of carbon from "carbonate" solutions results in an increase in OH^- concentration which is indicated by a rising pH. By allowing aquatic plants to photosynthesize in a closed system, causing the gradual depletion of their carbon supply, considerable information can be gained as to their capabilities for carbon acquisition.

This technique, which may appear to be highly artificial in its treatment of the plant, is in many respects a realistic synthesis of field conditions where plants are exposed to conditions of partially, to highly, depleted carbon supplies, frequently coupled with high oxygen concentrations.

During photosynthesis, the pH rises until a steady state is reached, which can be interpreted as the total-carbon compensation point for the species under the conditions of the experiment. Fig. 9 shows pH curves for two microalgae and three macrophytes in a 1 m-equiv. l^{-1} alkalinity solution. These maximum pH values reached by a species tend to be very reproduceable and appear to be one of the most reliable of the parameters measured. There appear to be two groups, the microalgae, which are able to generate pH values well above 10, and the macrophytes, a group which achieved significantly lower pH levels. The final HCO_3^- and CO_2^* concentrations at the final pH reached by each species are given in Table 7 .

Fig.10 shows the effect of a range of alkalinity values on the rate of change in pH and on the final pH achieved by *Elodea canadensis*. The pH of 10.00 reached in 2 m-equiv l^{-1} is consistantly less than the final pH of 10.6 reported by Ruttner

FIGURE 9

pH increases during photosynthesis in a solution containing 1 m-equiv l^{-1} alkalinity. *Anabaena* (—·—·—·—); *Cosmarium* (————); *Elodea* (·····); *Eurhynchium* (·····) and *Fontinalis* (— — — —). Dashed line at pH 11.1 represents the maximum pH attainable when C_T concentration reaches zero.

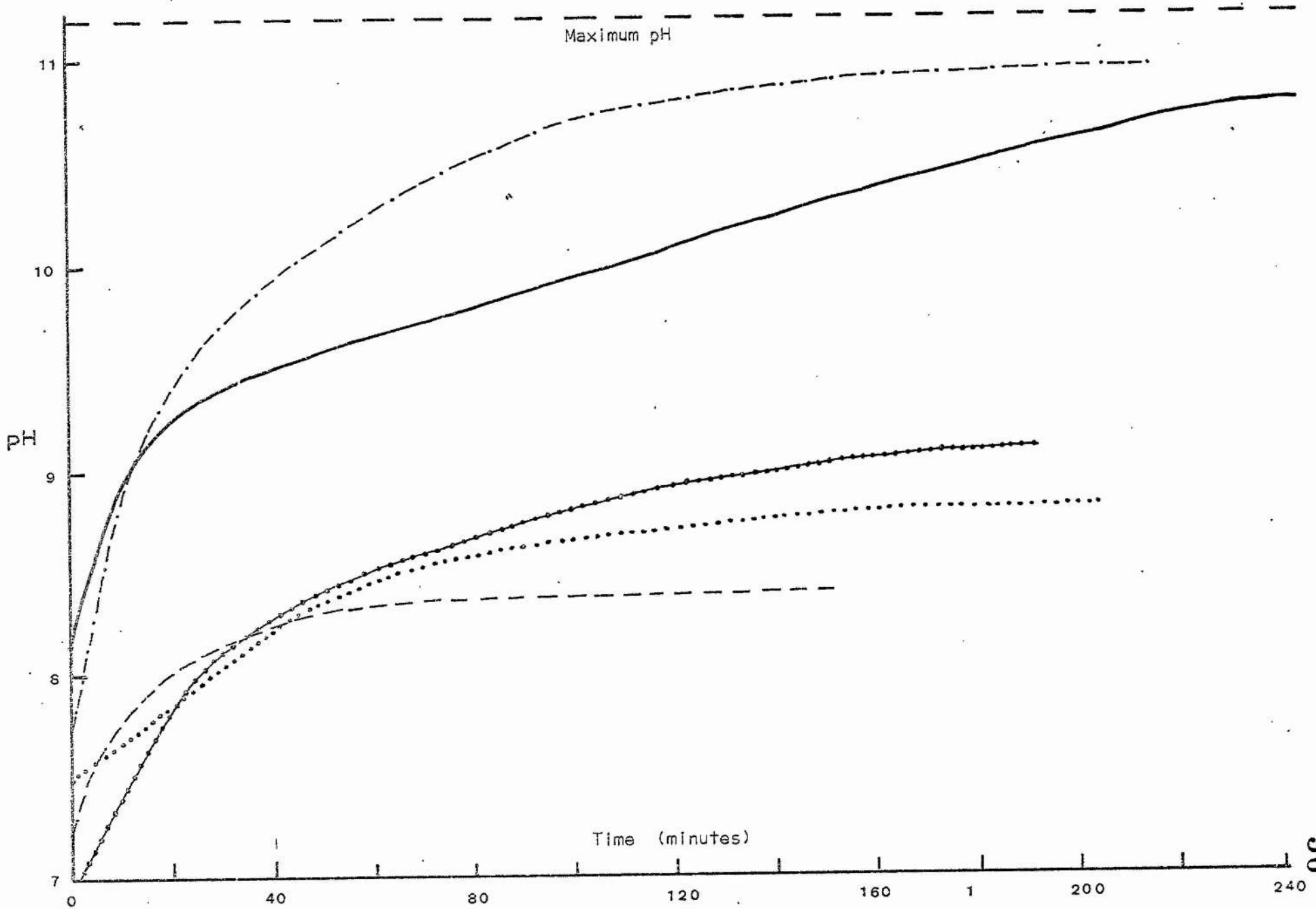
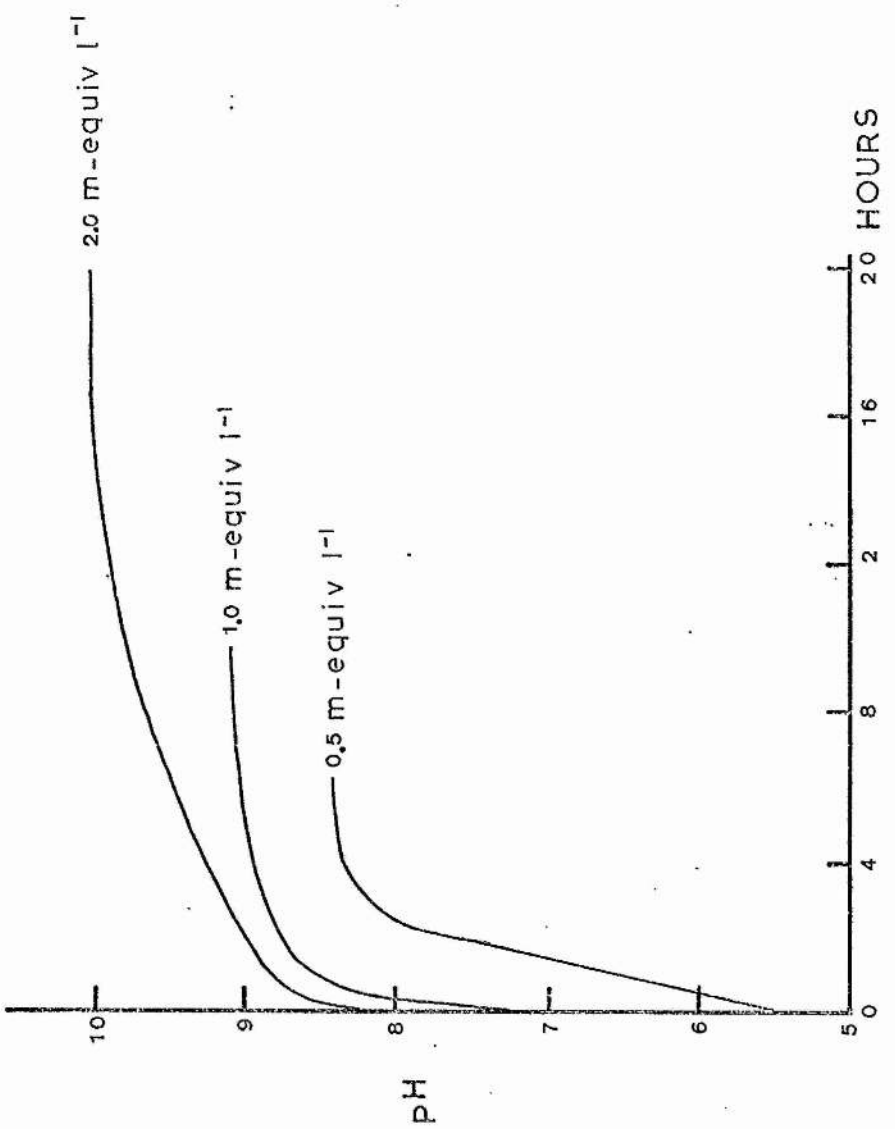

Maximum pH
11
10
9
8
7
pH
0
40
80
120
160
1
200
240
Time (minutes)

FIGURE 10

pH increases produced by *Elodea* during photosynthesis in 3 levels of alkalinity.


2.0 m-equiv l⁻¹
1.0 m-equiv l⁻¹
0.5 m-equiv l⁻¹
pH
10
9
8
7
6
5
0
4
8
2
16
20
HOURS

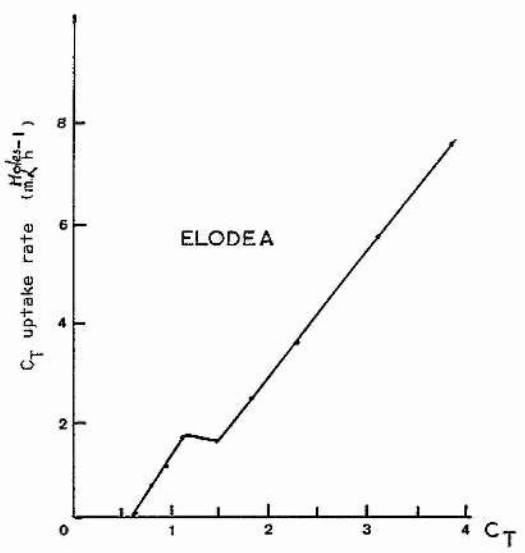
(1947) in the same type of experiment with *Elodea* in a bicarbonate solution with an alkalinity of 1 m-equiv l^{-1}. In the present experiments, the initial rate of pH change was increased about $2\frac{1}{2}$ times when the alkalinity was doubled from 0.5 to 1 m-equiv l^{-1} and a further $2\frac{1}{2}$ times when the alkalinity was redoubled; while the final pH increased from 8.38 to 9.15 to 10.00. This can be compared to the theoretical maximum pH at 20° reached on the removal of all inorganic carbon, being 10.87, 11.17 and 11.77 with alkalinities of 0.5, 1. and 2 m-equiv l^{-1} respectively (Fig. 4).

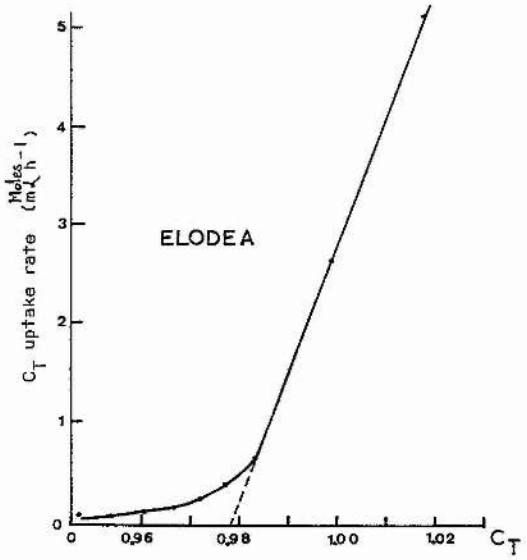
In a second set of experiments involving pH-drift, the rate of carbon uptake under conditions of constant alkalinity was calculated from the increase in pH with time. The change in C_T for each change of 0.1 pH unit was determined from the tables in Appendix III , and the time taken for this unit pH change was obtained from a plot of pH values against time. Rate of C_T uptake was then calculated for each pH interval: two sets of these data are presented in Fig 11 . The top row illustrates the rate of C_T uptake by *Elodea canadensis* at alkalinity values of 0.5, 1.0, and 2.0 m-equiv l^{-1}, in relation to C_T concentration in the bulk solution. The bottom row provides similar curves for *Eurhynchium rusciforme*, *Anabaena cylindrica* and *Fontinalis antipyretica*, all at an alkalinity of 1 m-equiv l^{-1}.

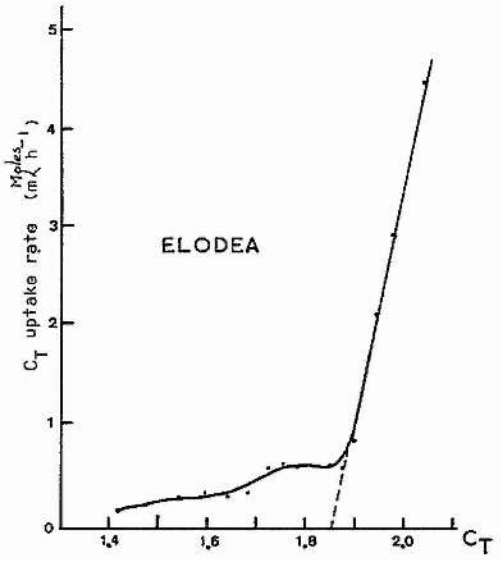
The plots of C_T uptake rate as a function of C_T concentration are linear (*Fontinalis*) or, like those of *Elodea* and *Eurhynchium* at 1 m-equiv l^{-1}, show a steep phase at higher C_T concentrations and a phase with smaller slope at lower C_T values. If alkalinity is lowered to 0.5 m-equiv l^{-1}, *Elodea* produces a straight line also, but an increase of alkalinity to 2 m-equiv l^{-1} extends the curvilinear phase to even smaller C_T values. The steep phase of the plot may be extrapolated to intersect with the C_T axis. The CO_2^* concentration and pH occurring at that point may then be determined from the C_T tables . Such an extrapolation for the curves of *Elodea* at alkalinities of 1 and 2 m-equiv l^{-1} yields equilibrium CO_2 concentrations of 4.3 and 3.1 μM respectively. Similarly at 0.5 m-equiv l^{-1}, the straight- line intercept yields 4.9 μM CO_2^*. These "intercept" CO_2^* concentrations so determined for *Elodea* appear to be fairly constant. Similar extrapolations were made for other species which showed the two-phase plot. "Intercept" concentrations

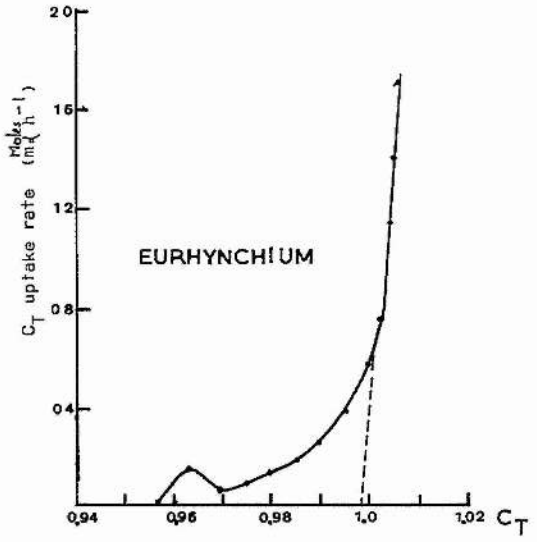
FIGURE 11

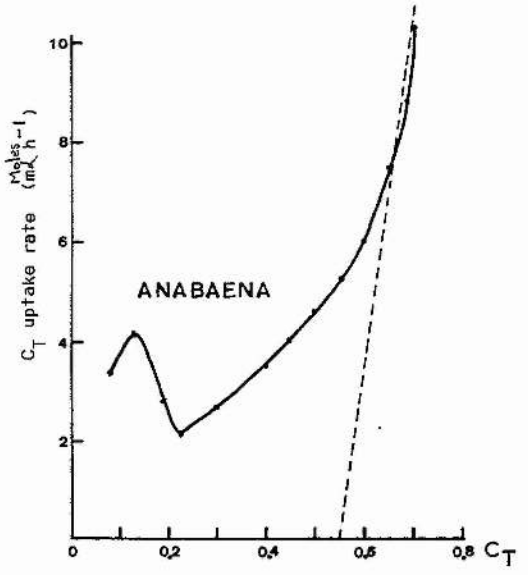
Rate of net C_T uptake by named species in relation to C_T concentration in the bathing solution during pH-drift experiments with alkalinity concentrations of 0.5, 1.0, and 2.0 m-equiv l^{-1} in the case of *Elodea* and 1 m-equiv l^{-1} for the remainder.

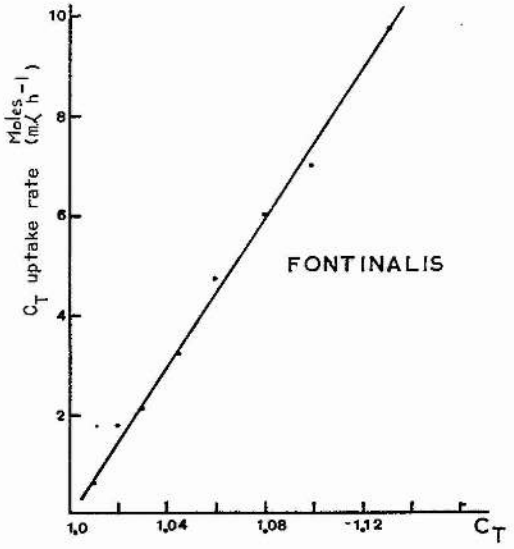

ELODEA
C_T uptake rate (Moles^{-1} mℓ h^{-1})
0
2
4
6
8
1
2
3
4
C_T


ELODEA
C_T uptake rate (Moles^{-1} mℓ h^{-1})
0
1
2
3
4
5
0,96
0,98
1,00
1,02
C_T


ELODEA
C_T uptake rate (Moles^{-1} mℓ h^{-1})
0
1
2
3
4
5
1,4
1,6
1,8
2,0
C_T


EURHYNCHIUM
C_T uptake rate (Moles^{-1} mℓ h^{-1})
04
08
12
16
20
0,94
0,96
0,98
1,0
1,02
C_T


ANABAENA
C_T uptake rate (Moles^{-1} mℓ h^{-1})
2
4
6
8
10
0
0,2
0,4
0,6
0,8
C_T


FONTINALIS
C_T uptake rate (Moles^{-1} mℓ h^{-1})
2
4
6
8
10
1,0
1,04
1,08
1,12
C_T

of CO_2^* (and bicarbonate) may or may not be distinct from "final" concentrations reached at the maximum pH achieved by a particular species. Final and intercept values of pH, CO_2^* and HCO_3^- are given for 18 species in Table 7 . No intercept values are given for those species which did not have a 2-phase C_T uptake plot.

Interpretation of intercept and final concentrations in pH-drift experiments.

The slope of the carbon uptake-C_T curves obtained from pH-drift experiments such as those shown in Fig. 11 , and the derived data on intercept and final concentrations of C_T and CO_2^* set out in Table 7 lead to the following interpretations. Plots may take two forms:

(1) A curvilinear plot of two phases which has a steep almost linear slope occurring at high C_T concentrations and a 'tail' of lower slope at lower C_T concentrations. This type of curve is produced when the plant has greatly differing affinities for bicarbonate and free CO_2 and is really a composite function resulting from the overlap of the kinetic curves for these two carbon species.. Extrapolation of the steep section to the C_T axis thus gives a value for C_T with an equilibrium CO_2^* concentration equal to the CO_2^* compensation point. The phase of the plot having a smaller slope at C_T concentrations below the CO_2^* compensation point represents bicarbonate use only.

(2) A plot which does not show two phases indicates two possible situations. (a) The plant does not use bicarbonate and the plot is the result of CO_2^* use only or, (b) the affinity for HCO_3^- is very similar to that of CO_2^* so that the kinetic curves coincide.

These two conditions may be separated on the basis of the final pH produced by the plant and consequently the final equilibrium CO_2 concentration. Those species which have a high affinity for HCO_3^- will continue to photosynthesize utilizing HCO_3^- when the CO_2^* concentration has fallen to very low levels ($< 1\mu M$) Those species which do not readily use bicarbonate will cease carbon uptake when the CO_2^* concentration has fallen to the compensation point ($\approx 4\mu M$) leaving a considerable concentration of bicarbonate unused.

TABLE 7

Intercept and final concentrations in pH-drift experiments.

Species	Intercept C_T					Final C_T				Intercept $[CO_2^*]$ / Final $[CO_2^*]$
	Alk m-equiv liter^{-1}	pH	C_T (mM)	HCO_3^- (mM)	CO_2^* (μM)	pH	C_T (mM)	HCO_3^- (mM)	CO_2^* (μM)	
Anabaena cylindrica	1	10.25	0.59	0.31	4×10^{-2}	10.97	0.19	0.01	8×10^{-4}	50
Microcystis aeruginosa	1					10.9	0.25	0.02	6.3×10^{-4}	
Fragilaria crotonensis	1					10.75	0.35	0.06	2.5×10^{-3}	
Melosira italica	0.4					9.8	0.35	0.27	9.2×10^{-2}	
Asterionella formosa	0.4					9.7	0.37	0.30	1.3×10^{-1}	
Cosmarium botrytis	1	9.3	0.90	0.81	9×10^{-1}	10.78	0.34	0.05	3.4×10^{-3}	265
Chlorella emersonii	0.5					10.70	0.07	0.02	1.2×10^{-3}	
" "	1					11.04	0.05	0.008	4.3×10^{-4}	
" "	2	8.9	1.91	1.83	5	11.23	0.44	0.04	5.5×10^{-4}	9000
Nitella flexilis	2					8.84	1.93	1.85	6.0	
Chara vulgaris f. contraria	2	8.60	1.963	1.91	10.8	8.96	1.90	1.81	4.7	2.3
Fontinalis antipyretica	1					8.45	0.99	0.97	7.9	1
" "	2					9.05	1.89	1.79	4.0	1
" "	4	8.9	3.82	3.63	8	9.24	3.63	3.26	4.0	2
Eurhynchium rusciforme	1	8.6	0.98	0.96	5.5	8.91	0.96	0.92	2.6	2.1
Elodea canadensis	0.5	8.35	0.50	0.49	4.9	8.35	0.50	0.49	4.9	1
" "	1	8.7	0.97	0.95	4.3	9.17	0.92	0.85	1.2	3.6
" "	2	9.1	1.87	1.74	3.1	10.00	1.40	0.89	0.2	1.6
Hippuris vulgaris	1					8.73	0.97	0.94	4.03	1
" "	2					9.01	1.90	1.79	4.0	1
" "	4					9.48	1.73	1.48	1.1	1
Potamogeton crispus	2	8.6	1.96	1.91	10.7	9.52	1.71	1.44	0.98	10.9

If these interpretations are correct and the intercept CO_2^* is the CO_2 compensation point it should be constant over a range of alkalinities and for *Elodea* this holds. The intercept CO_2^* concentration lies between 3.1 and 4.9 over the alkalinity range of 0.5 to 2 m-equiv l^{-1}. At the maximum pH to which *Elodea* can take a solution of given alkalinity, the final $[CO_2^*]$ should then decrease with increasing alkalinity because further removal of HCO_3^- increases the pH and indirectly causes the equilibrium CO_2 concentration to drop to extremely low levels (0.2 μM in the case of *Elodea* in 2 m-equiv l^{-1} alkalinity). If the original bicarbonate concentration is above the compensation point when the CO_2 compensation point is reached, uptake will continue until the HCO_3^- concentration falls to the bicarbonate compensation point. If the alkalinity is too high, the pH may rise to the point where it inhibits further bicarbonate uptake. This occurs when *Chlorella* reaches pH 11.2 in 2 m-equiv l^{-1} alkalinity and leaves behind 0.44 mM C_T whereas in lower alkalinities it leaves 0.3 to 0.7 mM.

The response of *Fontinalis antipyretica* was also examined in a range of alkalinity concentrations as it is regarded as the classic non-user of bicarbonate. At 1 m-equiv l^{-1}, by the above interpretations, there appears to be no bicarbonate use: the plot of carbon uptake *vs.* C_T concentration is linear and the intercept and final C_T values are the same up to 4 m-equiv l^{-1} alkalinity. As would be predicted, increase in alkalinity brings no consistent change in intercept CO_2^* concentration and no difference between intercept and final CO_2^* concentration, but there is a steady increase in the final HCO_3^- concentration. The final CO_2^* concentration remains constant near 4 μM. This constancy of the final CO_2^* concentration indicates that in the case of *Fontinalis*, the use of bicarbonate does not occur to an appreciable extent where the bicarbonate concentration is under at least three millimolar. An indistinct bicarbonate 'tail' did appear in 4 m-equiv l^{-1} alkalinity giving an intercept CO_2^* concentration of 8 μM, thus indicating that bicarbonate use might start at a concentration of $\approx$3.8 mM. This would agree with the results of the kinetic experiments. A pH-drift experiment at an alkalinity greater than 4 m-equiv l^{-1} would be required to obtain a more accurate set of intercept concentrations.

Other species examined lie between the extremes set by *Anabaena* and *Chlorella* representing those species which have a high affinity for bicarbonate and *Fontinalis* and *Hippuris* which use bicarbonate only when present in rather high concentrations.

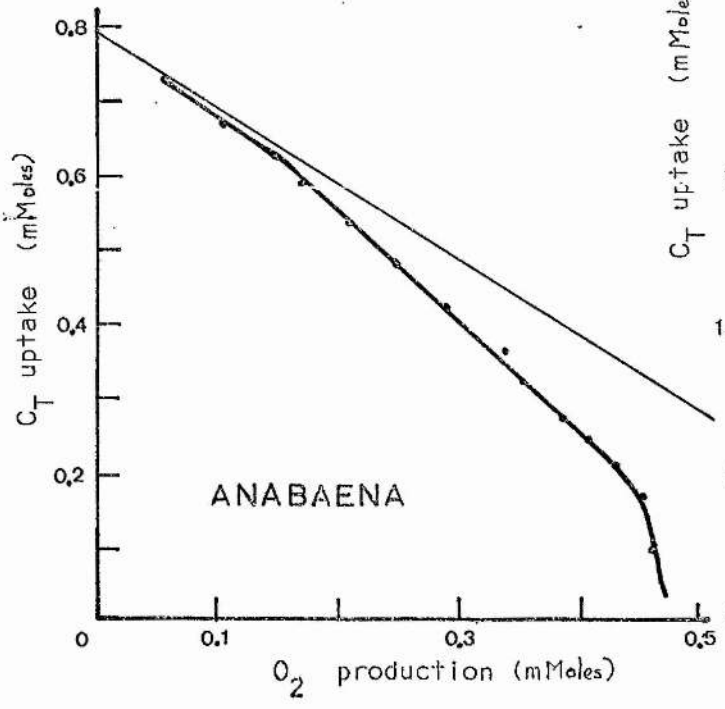
Validity of the pH-drift experiments.

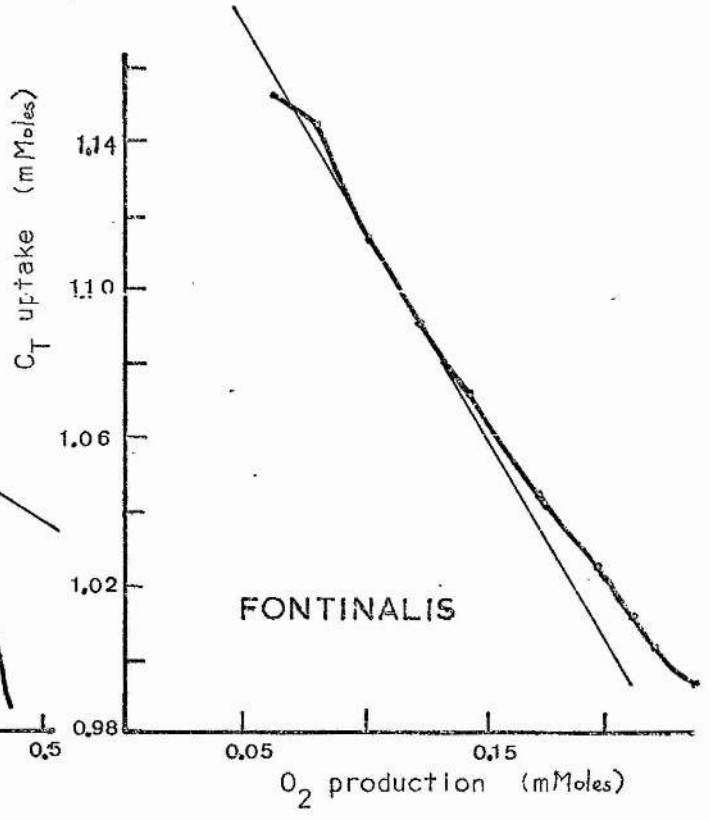
The most serious objection to the validity of the pH-drift experiments arises from the high oxygen concentrations produced during photosynthesis and the effect of this oxygen on respiration. Large amounts of oxygen are produced in bathing solutions of high alkalinity by species which are able to use a high proportion of the available carbon. As oxygen concentration was monitored during the pH-drift experiments it was possible to determine the ratio of CO_2 taken up to oxygen released (assimilatory quotient) as a check. Fig. 12 shows how this ratio varied in 4 species as the C_T concentration decreased and the oxygen concentration increased. A line with a slope of -1 represents an assimilatory quotient of unity. Macrophytes nad assimilatory quotients near 1 during the experiment. Initial discrepancies in oxygen production which occurred at the beginning of an experiment as shown by *Elodea* were likely due to gas stored in the aerenchyma. After this initial period lasting only a few minutes, the assimilatory quotient returned to unity. *Fontinalis*, lacking aerenchyma, had a quotient of 1 throughout. *Anabaena* produced less oxygen than predicted, the assimilatory quotient rising to 1.4 as the oxygen concentration rose. This might be attributed to photorespiration. The alkalinity sometimes fell by 10-20% during the experiment which might be caused by the release of organic acids into the bathing solution. In some pH-drift experiments using old *Anabaena* cultures, lysis occurred when the pH reached 10.3 resulting in a cessation of oxygen production and a net uptake of oxygen in the light. Younger cultures started from inocula grown in nitrogen-free medium did not lyse. Lysis at high pH values may be brought about by lytic bacteria frequently found in the algal sheath which may grow rapidly, utilizing photosynthates leaving the algal cells.

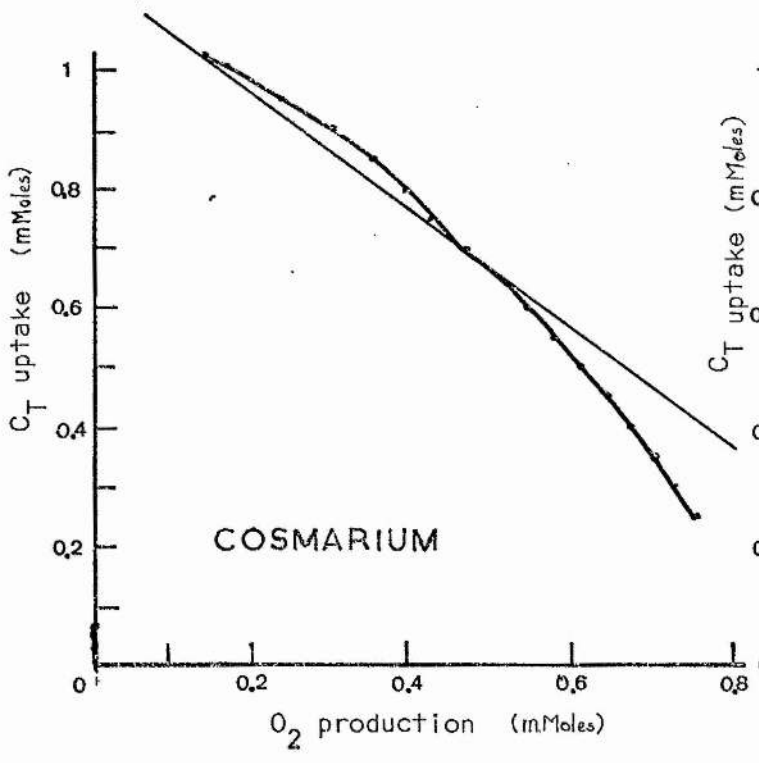
The second problem concerns the accuracy with which the concentrations of the individual carbon species may be found from a knowledge of the alkalinity and the pH.

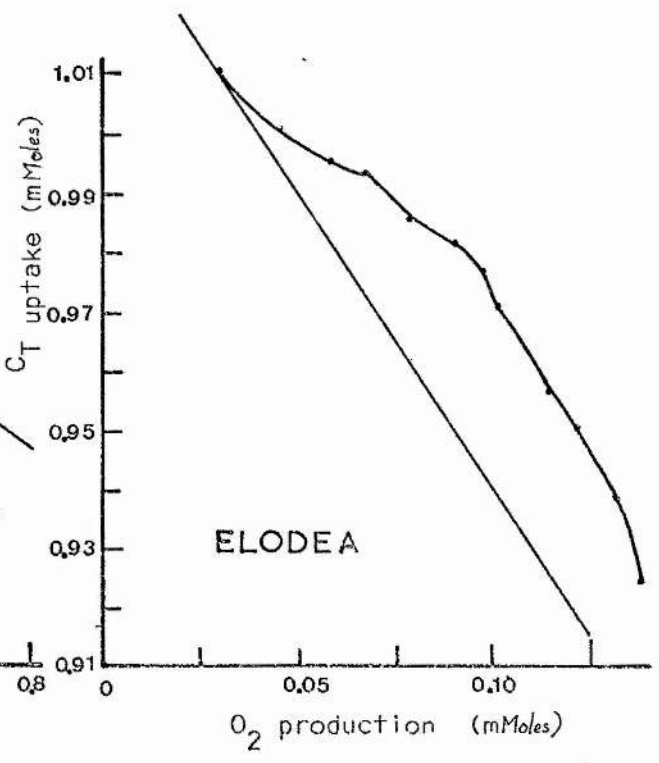
FIGURE 12

Total carbon uptake and simultaneous oxygen production (mMoles) during pH-drift experiments with named species. The straight line represents an assimilatory quotient (CO_2 uptake/ O_2 produced) of -1.


ANABAENA
C_T uptake (mMoles)
0.8
0.6
0.4
0.2
0
0.1
0.3
0.5
O_2 production (mMoles)


FONTINALIS
C_T uptake (mMoles)
1.14
1.10
1.06
1.02
0.98
0.05
0.15
O_2 production (mMoles)


COSMARIUM
C_T uptake (mMoles)
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
O_2 production (mMoles)


ELODEA
C_T uptake (mMoles)
1.01
0.99
0.97
0.95
0.93
0.91
0
0.05
0.10
O_2 production (mMoles)

Slight errors in the measurement of pH can greatly affect the calculated concentrations of CO_2^*, HCO_3^- and CO_3^{2-} particularly at very high pH values above 10.5. The calibration of the pH electrode must be carefully attended to, using two buffers at the temperature of the experiment with temperature corrections applied. The tables used to calculate the concentrations of the carbon species must be based on good values for the ionization constants, again corrected for temperature and the effects of total salt concentration. Fortunately these constants have been extensively investigated and are known with some accuracy (Kern, 1960).

Thirdly, the results of the pH-drift experiments are based on the principle of constant alkalinity. There is no means of determining alkalinity during the course of an experiment but it is desirable to determine the alkalinity before and at the end of an experiment to check that large changes have not taken place. In most experiments perfomed, the final alkalinity was 95% or more of the starting alkalinity. Plants which consummed most of the carbon occasionally lowered the alkalinity by as much as 20% if the original alkalinity was small and the experiment was started at a C_T concentration which had been enriched by the addition of CO_2. This loss of alkalinity can be roughly corrected for in the calculations at least for the final concentrations, though in cases where the loss of alkalinity was high the experiment was usually discarded. Obviously the determination of very small free CO_2 concentrations on the basis of alkalinity and pH is not the most accurate and it would be desirable to determine these concentrations more directly by the use of a properly calibrated CO_2 gas analyser.

In spite of these shortcommings, the technique provides results of good reproducibility, particularly at the point of maximum carbon depletion. The composition of the bathing solution is continuously known (unlike methods based on the uptake of ^{14}C), the measurements being made without disturbing the system or destruction of the plant.

Evidence that the pH of the bulk solution at the final pH achieved during photosynthesis approaches the pH existing at the cell surface is provided by Lucas and Smith (1973) who measured the pH at the surface of *Chara coralina* and found that the

pH of the alkaline bands reached 8.8, which is close to the value of 8.96 for *Chara* in 2 m-equiv l^{-1}.

Summary of the uptake experiments.

The results of pH-drift experiments on 18 species of aquatic plants have shown that there exists a considerable range in the abilities of aquatic plants to utilize the carbon supply available to them through the water. Starting from air equilibrium, *Chlorella* is able to use 95% of the total carbon in a solution containing 2 m-equiv l^{-1} alkalinity while *Hippuris* and *Fontinalis* can only use 5%. The species examined were chosen to represent a range of types which hopefully represent most of the naturally occurring range. The differing abilities of aquatic plants to use their carbon supply leads to potential competition and consequent deprivation which would have successional and ecological implications.

Those species which are able to extract over 90% of the carbon from the bathing solution leave no doubt as to their ability to use bicarbonate and indeed carbonate. It is suggested that one category of "users" and another of "non-users" does not exist, but that there is a graded series. Given amongst all the species tested in this study, higher diffusive resistances to CO_2 and lower affinities for HCO_3^- in the macrophytes than in the microalgae, the use of bicarbonate by these species depends upon there being rather high bicarbonate concentrations. Even species such as *Fontinalis* might use some bicarbonate in photosynthesis if the concentrations were high enough.

The final pH achieved by a plant at a particular alkalinity is possibly the most useful parameter which describes the carbon utilizing abilities of aquatic plants. Those species which cannot reach pH values above about pH 9.5 at natural levels of alkalinity (< 4 m-equiv l^{-1}) tend to use carbon until a CO_2^* compensation point is reached. Some bicarbonate may be used if concentrations are high enough and all the macrophytes examined fall into this category. It follows that the CO_2^* compensation point will be a fair measure of the carbon- extracting capacity of these macrophytes in natural

waters. Other species typified by some of the microalgae readily use bicarbonate to low concentrations and can raise the pH of the system to 10 or 11. Obviously, therefore, the macrophytes will be able to obtain little or no carbon once the bicarbonate-using species raise the pH to the point where the free CO_2 concentration is below their compensation point.

PART II

THE INTERACTIONS OF AQUATIC PLANTS AND THE CARBONATE SYSTEM IN LAKES.

In Part I the performance of submerged aquatic plants was investigated by manipulating the composition of the bathing solution in a system closed to the atmosphere. In Part II the properties of the carbonate system in natural waters will be discussed along with the relationship between plants and the carbonate system open to the atmosphere, aiming towards a classification of lake types and the plant communities which characterize them.

Origin of alkalinity in lakes and its role in affecting total carbon concentrations.

In nature, water acquires carbonate alkalinity directly from the dissolution of rocks by water with the additional aid of CO_2 and SO_2 picked up from the atmosphere. A whole range of carbonaceous minerals occur which exhibit considerable differences in solubility. In addition these minerals will determine the proportions of metal cations present in the water notably calcium and magnesium. The geology and hydrology of the drainage basin and the flushing rate determine the amount of inorganic carbon present in a lake. Frequently lakes near the sea receive considerable amounts of carbonate from wind-borne marine sands. Naturally occurring alkalinity levels range from about 5 m-equiv l^{-1} in extremely hard-water lakes such as Lawrence Lake described by Wetzel (1975) to zero in acid waters. Alkalinity may be increased by the addition of OH^- from industrial wastes, particularly some papermill effluents. More commonly acids are added to waters and these destroy alkalinity. Sources may be from mine wastewaters, and acid rain produced by volcanic activity and by the burning of sulphur-rich fuels.

In the open system where CO_2 can be gained or lost to the atmosphere, the total carbon will tend to approximate the alkalinity when the system is in equilibrium with the air. A decrease in pH brought about by the addition of acids increases the $[CO_2^*]$ resulting in the loss of CO_2 to the atmoshere. Conversely C_T can be increased by the addition of OH^-. Water inflows originating from areas of acidic rocks or peat bogs would lower the total carbon concentration of the water in a lake even when its basin might lie on calcareous rock.

Determination of alkalinity, total carbon and free CO_2 in natural waters.

The 'carbonate system' has been described for simple dilute solutions in Part I. Natural waters are considerably more complex in composition and this will affect activities and ionization constants as well as introducing other components contributing to alkalinity, which under conditions of high pH produce an over-estimation of C_T (Talling 1973). To define the carbonate system in a body of water at a given time, five parameters must be measured; total alkalinity, total inorganic carbon, pH, temperature and conductivity. Concentrations of CO_2^*, HCO_3^- and CO_3^{2-} may be estimated from pH and C_T, using the ionization fractions corrected for temperature and the effects of total solute concentration.

The simplest determination is an acidimetric titration of a water sample to pH 8.3 (phenolphthalein endpoint) followed by further titration to pH 4.6 (methyl red endpoint) which give $[CO_3^{2-} + OH^-]$ and $[HCO_3^- + CO_3^{2-} + OH^-]$ respectively. These titrations, usually carried out with dilute solutions of strong acids, produce endpoints which are not very sharp and are shifted by temperature and the presence of other solutes. Some analytical techniques attempt to define the endpoints more precisely by applying correction factors based on the original pH of the sample and the conductivity (a function of total solute concentration) (Golterman 1969). The 'methyl orange endpoint' may vary from about pH 5.3 to 4.5 over the total carbon concentration range of 0.05 to 2.0 mM. All acidimetric titrations include titratable bases such as $H_3SiO_4^-$, $H_2BO_3^-$, HS^- and, most importantly, particulate $CaCO_3$.

An evaluation of the relative errors in the measurement of the parameters capable of direct analysis is given in Stumm and Morgan (1970 p. 142). None of the individual carbon species can be determined directly by acidimetric titration. Free CO_2 itself may be found by alkalimetric titration.

A method of determining the endpoints by means of a stepwise titration has been described by Gran (1952) and has been treated further by Dryssen (1965) and Talling (1973). The Gran titration locates the endpoints applicable to the sample

being titrated and interpolates to give the volume of acid added at the endpoint. It has the added advantage of using the relative change in electrode potential during the titration rather than absolute pH measurements which, in normal titrations to fixed endpoints, require the pH meter to be calibrated against buffers. Dryssen shows how the $[H^+]$ of the sample may be determined without the necessity of a calibrated pH meter. The procedure for carrying out a Gran titration is given in Appendix II

Free CO_2 concentration at air-equilibrium.

The open carbonate system when in equilibrium with the CO_2 in the atmosphere has a CO_2 concentration determined by the partial pressure of atmospheric CO_2 and the distribution constant K_D, which is the concentration ratio of CO_2 in the gaseous and aqueous phases.

$$K_D = \frac{[CO_{2(aq)}]}{[CO_{2(g)}]} \qquad (1)$$

CO_2 concentration in the atmosphere is derived from its partial pressure:

$$[CO_{2(g)}] = \frac{p_{CO_2}}{RT} \qquad (2)$$

where RT is the gas constant. Combining (1) and (2) gives

$$[CO_{2(aq)}] = \left(\frac{K_D}{RT}\right) p_{CO_2}$$

Since $\frac{K_D}{RT}$ is a constant at a given temperature it can be expressed as K_H (Henry's law constant) having the units moles litre^{-1} atm^{-1} and

$$[CO_{2(aq)}] = K_H \, p_{CO_2}. \qquad (3)$$

The partial pressure of CO_2 in the atmoshere is

$$p_{CO_2} = x^{CO_2} (P_A - w) \qquad (4)$$

where: x^{CO_2} = volume fraction of CO_2 in dry air
P_A = atmospheric pressure
w = water vapour pressure

Current estimates of CO_2 concentration in the atmosphere measured in remote areas yield CO_2 concentrations of 330 ppm giving $_{x}CO_2$ a value of 3.30×10^{-4} atm. The value of w may be obtained from relative humidity (R_h) and tables of water vapour pressure:

$$w = R_h \cdot vp$$

A table of K_H and vapour pressure values over a range of temperature is given in Appendix I . $CO_{2(aq)}$ concentration at 20° is about 12.6 μM compared to 14.7 μM in the air.

A water of given alkalinity in comming to air equilibrium will exchange CO_2 with the atmosphere until the $K_H\, p_{CO_2(air)} = CO_{2(aq)}$ and in so doing C_T and pH will adjust to a value fixed by p_{CO_2} and temperature. For a given alkalinity the condition

$$Alk = \frac{K_H \cdot p_{CO_2}}{\alpha_o}(\alpha_1 + 2\alpha_2) + [OH^-] - [H^+] \qquad (5)$$

exists. By the use of the tables in Appendix III the equation can be solved to give pH at air-equilibrium (Fig.13). This pH is of value in determining the concentrations of the individual carbon species at air-equilibrium. The air-equilibrium pH may be determined empirically by bubbling air through a solution of known alkalinity. These measured values are also shown in Fig. 13 and are lower than predicted by equation (5), corresponding to a $[CO_{2(aq)}]$ of about 14 μM rather than the 12.6 μM calculated. The empirical values also apply to a number of natural freshwaters tested.

At a given pH, a solution in equilibrium with CO_2 in the gas phase will have a fixed C_T concentration given by

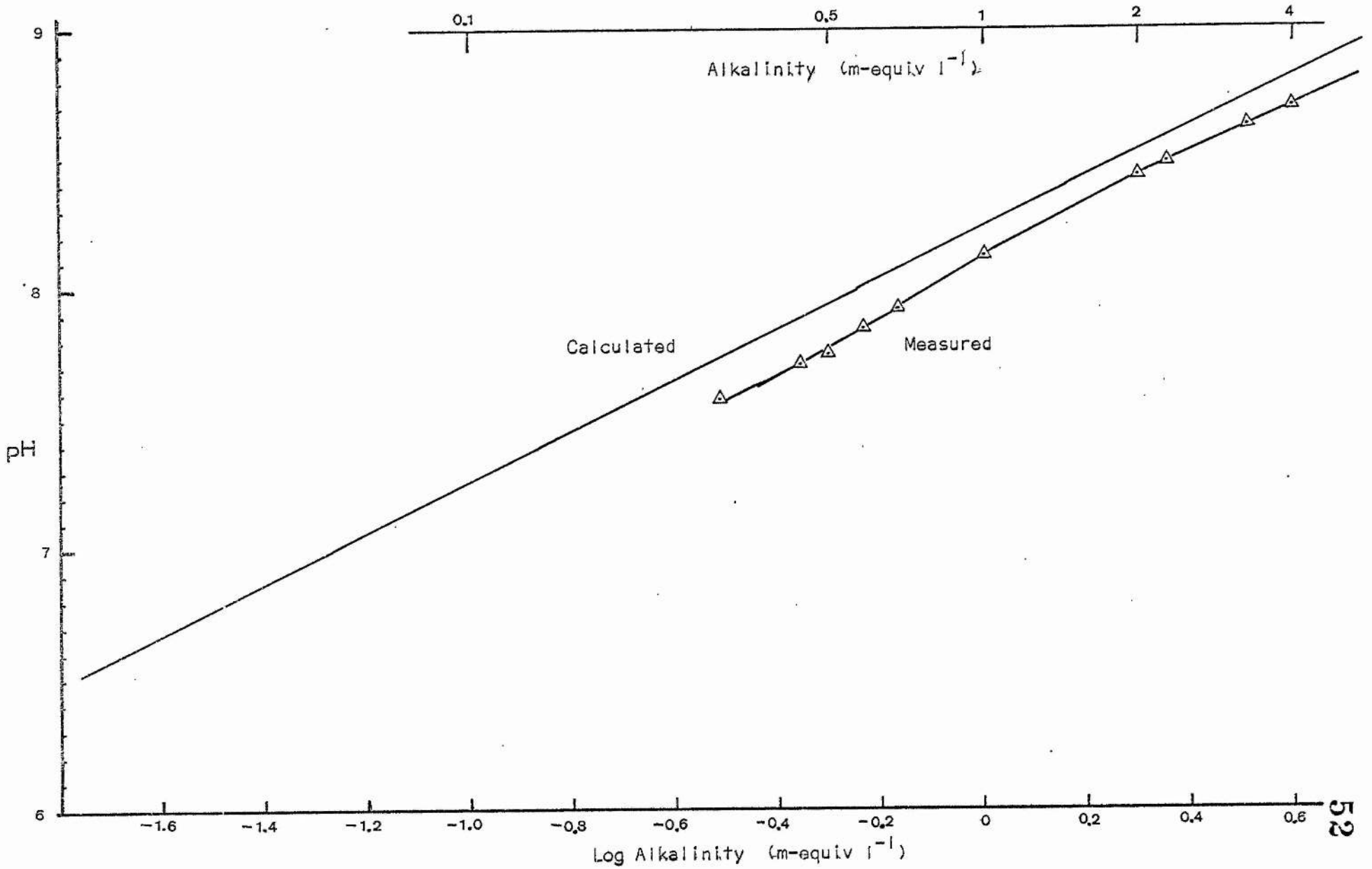
$$C_T = \frac{K_H\, p_{CO_2}}{\alpha_o} \qquad (6)$$

C_T equals alkalinity when the term $\alpha_1 + 2\alpha_2 = 1$, which occurs about pH 8.3.

During sunny weather, with a sufficiently large phytoplankton or macrophyte community, the total carbon concentration may be considerably lowered. The consequent increase in pH lowers the free CO_2 concentration to levels which may be below

FIGURE 13

Relationship of pH to alkalinity when the solution is in equilibrium with the CO_2 in the air.(3.3×10^{-4} atm.). The second plot represents measured pH values in aerated natural and prepared water samples of known alkalinity.


0.1
0.5
1
2
4
Alkalinity (m-equiv l⁻¹)
9
8
7
6
pH
Calculated
Measured
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
Log Alkalinity (m-equiv l⁻¹)

the compensation point of some of the plants. The carbon surplus or deficit characterizing a water is the difference between the measured C_T and the C_T concentration at air equilibrium obtained from the air-equilibrium pH at the alkalinity of the water (equation 5 or Fig.). and equation 6.

Predictions of C_T concentration in natural waters, based on total alkalinity from titrations and pH, are liable to give estimates of C_T which are too great when the pH is over 8.5. This is due to the presence of titratable bases such as silicates in fresh water which are included in the alkalinity determined by titration. The amount of non-carbonate alkalinity may be estimated from a comparison of measured $C_T/Alk_{(total)}$ with the calculated $C_T/Alk_{(carbonate)}$ ratios. Equation (7) is modified from Talling (1973) and can be used to determine non-carbonate alkalinity. Measurements must be obtained from the titration of a sample where pH is greater than 8.5 and preferably higher. This may be produced through photosynthetic activity or by purging with CO_2-free gas.

$$\frac{X}{Alk_{(total)}} = 1 - \frac{C_T(\alpha_1 + 2\alpha_2)}{Alk_{(tot)} - [OH^-]} \cdot \frac{Alk - [OH^-]}{Alk_{(total)}} \qquad (7)$$

The carbonate alkalinity $Alk' = Alk_{(total)} - X$ and is used to calculate C_T at any pH over 8.5 from

$$C_T = \frac{(Alk' - X) - [OH^-] + [H^+]}{\alpha_1 + 2\alpha_2} - \frac{X}{\alpha_{Si^-}} \qquad (8)$$

where: $$\alpha_{Si^-} = \frac{[H^+]}{K_{Si} + [H^+]} \quad \text{and} \quad K_{Si} = 3.16 \times 10^{-10}$$

Equation (8) assumes that X is primarily due to silicates; however, other bases such as borate in seawater can also be taken into account by the appropriate term.

The effect of these titratable bases in fresh-waters is not inconsiderable when pH rises to 10, as can occur

during bloom conditions, and errors in the calculated values of C_T may be significant in studies of carbon uptake by plants carried out using natural waters.

Acidimetric titration of natural waters also includes carbonates in the solid phase, in the estimates of alkalinity and C_T. At high pH when colloidal or particulate carbonates occur, the ionized fraction of C_T will be less than calculated and estimates of CO_2^* and HCO_3^- based on measured C_T will be too high. The problems of carbonate precipitation will be dealt with later.

CO_2 exchange with the atmosphere.

The exchange of CO_2 across the air-water interface is the most poorly understood parameter of the carbonate system. The rates of exchange have been discussed by Schindler (1975). The exchange of CO_2 depends upon the mass transfer coefficient (M) of the gas and the difference in concentration between the gaseous and aqueous phases.

$$M = \frac{D}{Z}$$

where D is the diffusion coefficient of the gas ($1.91 \times 10^{-5} cm^2 s^{-1}$ at 25° for CO_2) and Z is the thickness of the stagnant boundary layer. Z is dependent upon turbulence and estimated thickness vary from 20 microns in the North Pacific (Peng *et al*, 1974) to 800 microns in lakes (Thurber & Broecker, 1970) and varies inversely as the square of the wind velocity at the water surface. (Kanwisher, 1963, Emerson, 1975b, and Broecker & Peng 1974). M is also affected by impurities on the water surface.

Emerson (1975a) describes what he terms the chemical enhancement factor, E. This factor increases with the pH of the surface water and the thickness of the boundary layer, due to the increased probability of an incomming CO_2 molecule reacting with an OH^- while passing through a thicker boundary layer. Emerson found enhancement factors of 5 to 10 in Lake 227, after an enrichment experiment which had raised the pH to about 10 through photosynthetic activity.

The total flux across the air-water interface then becomes

$$J = E \frac{D}{Z} \quad CO_{2(atm)} - CO_2^* \qquad (9)$$

Values for CO_2 flux for the sea have been measured in the range of 0.33 to 1.08g $Cm^{-2}day^{-1}$ and up to 4.5 g m^{-2} day^{-1} in lakes.

The CO_2 flux is in practise difficult to measure without disturbing the system by affecting the wind velocity over the water surface and the mixing of the water column. Additional problems arise from the metabolic activities of organisms. To avoid the biological complications, some measurements have been based on the transfer rate of radon, (Emerson 1975b).

Tables 8a and 8b serve to illustrate the depletion phenomenon and its affects on the free CO_2 concentration in the water. Table 8a gives the main parameters of the carbonate system in three Scottish lochs after 48 hours of heavy cloud. Chlorophyll a content and nitrate concentration are given to indicate the abundance of the phytoplankton population and the current nutrient status. In contrast, Table 8b presents similar data from a series of lochs on a sunny day following 4 sunny days. The C_T concentrations in the three lochs during cloudy weather are near or above air-equilibrium. At the time of sampling, Black Loch contained a dense population of *Ceratium hirundinella* which had depleted the nitrate to unmeasureable concentrations. During cloudy weather this population and sediment respiration would release enough CO_2 to raise its concentration well above air-equilibrium, as observed. Even after several sunny days, Black Loch still retained a C_T surplus of 0.18 mMoles $litre^{-1}$. This is probably due to the shallowness of the euphotic zone caused by light reduction by the *Ceratium* ($E_{400-700nm}$ was 2.32) and by the deep brown colour of the water ($E_{400-700nm}$ = 1.7 in the absence of phytoplankton). The proportion of the total water within the euphotic zone is quite small.

Forfar Loch provided an unusual example of a potentially rich water with 13.8 mg NO_3^- $litre^{-1}$ and a high alkalinity (2.76 m-equiv l^{-1}). Sewage from the town of Forfar has affected the loch, causing heavy eutrophication. At the time of sampling, *Potamogeton pectinatus* was the only rooted aquatic species observed and there was little phytoplankton. The values given in the table represent

TABLE 8

8a Parameters of the carbonate system in three lochs after 48 hours of heavy cloud. Carbon surplus or deficit is the difference between measured C_T and the calculated C_T at air- equilibrium at the alkalinity prevailing at the time of sampling.

8b Lochs sampled on a sunny day which followed four days of bright sun.

TABLE 8a

Loch	Temp	pH	Alk m-equiv l^{-1}	C_T mM	CO_2^* μM	Air-equil pH	C surplus or deficit	Conductivity (25°)	NO_3^- ppm	Chlorophyll a mg M^{-3}
Leven	16	8.40	1.410	1.386	12.2	8.28	-0.240	.292	2.42	29
Black	16	7.23	1.713	1.878	26.8	8.45	+0.175	298	Nil	150
Lindores	17.5	8.65	1.687	1.604	7.85	8.34	-0.079	345	0.16	13

TABLE 8b

Mariee	19	9.26	0.685	0.570	0.7	7.92	-0.131	185	5.8	4.4
Clunie	20	9.00	0.585	0.510	1.1	7.85	-0.089	125	2.8	6.8
Butterstone	23	8.92	0.430	0.380	1.1	7.71	-0.068	129	Nil	7.6
Craiglush	20	7.55	0.305	0.325	19.6	7.58	+0.003	105	Nil	1.7
Lowes	19.5	8.79	0.340	0.320	1.13	7.61	-0.038	111	Nil	10.0
Forfar	18.5	8.20	2.755	2.745	37.8	8.61	+0.033	616	13.8	3.0
Rescobie	21.5	8.93	2.060	1.855	4.4	8.48	-0.185	375	Nil	21
Balgavies	21	9.20	1.790	1.595	2.1	8.42	-0.186	351	0.7	49
Black	17.5	7.3	1.865	2.032	26.2	8.41	+0.178	311	Nil	136

the open water and show a considerable surplus of carbon. However, in mats of *Cladophora* occurring in the loch, the pH within the first 4 cm of water was about 10.9. Here the total carbon concentration has been reduced to about 50% of the air-equilibrium concentration.

Craiglush Loch, with a very low phytoplankton population and a very sparse macrophyte community, represents a loch where the photosynthetic activity was very low during this period and the loch was in equilibrium with the air.

Clearly, in many lakes where there is a plant population of even a modest size, the rate of carbon uptake in the euphotic zone can exceed the input from the atmosphere and the hypolimnion, and slight to severe carbon depletion can arise.

Formation and precipitation of marl.

It is well known that considerable quantities of carbon may be lost through the precipitation of calcium carbonate as marl. This represents a loss of alkalinity which may not be readily reversible and may cause a loss of nutrients, particularly phosphates (Otsuki and Wetzel, 1972 and Schelske, 1962), which provides a likely explanation for the low phytoplankton densities occurring in marl lochs.

Carbonate precipitation occurs when the $[CO_3^{2-}]$ rises above the solubility of $CaCO_3$. The $[Ca^{2+}]$ which can remain in solution with $[CO_3^{2-}]$ is given by

$$[Ca^{2+}] = \frac{K_{so}}{C_T \alpha_2} \qquad (10)$$

Precipitation of $CaCO_3$ occurs when $C_T \alpha_2 = pK_{so}/2$.
Given a water of known alkalinity, the removal of CO_2 will raise the pH and consequently the CO_3^{2-} concentration to the point where $CaCO_3$ will precipitate. At 20° precipitation should begin when the pH values given below are reached.

Alkalinity (m-equiv liter^{-1})	pH
0.5	9.7
1	9.18
2	8.85
4	8.45

Magnesium carbonate is more soluble and is not precipitated under normal conditions in nature, marl being over 95% $CaCO_3$. Conditions of calcium carbonate supersaturation do occur. While the pH of the bulk solution may not be great enough to cause precipitation of $CaCO_3$, photosynthesizing plants can create a zone around the leaves where the pH is sufficiently high to cause marl to form. On macrophytes this occurs on the adaxial side of the leaves and in bands on charophytes (Lucas & Smith 1973). Under conditions of poor circulation, the carbonate is deposited on the leaves in a crystalline state which does not easily go back into solution, and may eventually fall to the sediments where it may be lost to the system, carrying phosphates with it. Marl sediments are often over 50% calcium carbonate (dry weight). The carbon depletion zones around micro-algae are small and easily dispersed. Solid calcium carbonate produced in these zones will be colliodal or very finely particulate and may quickly go back into solution once they leave the area of high pH.

Those species such as *Fontinalis* and *Hippuris* which do not readily use bicarbonate do not produce zones of high pH at the leaf surfaces like those plants which use some bicarbonate. Their leaf surfaces do not normally become marled even though other species in their vicinity may be heavily encrusted. Exceptions occur when marl settles on the leaves or nucleates there from supersaturated solution, or when epiphytes on the leaves produce marl. The amount of marl occurring on four macrophyte species in Loch Borralie expressed as a percentage of the ash weight is given in Table 9.

Interaction of the carbonate system with the plant community.

The combined effects of pH increase and carbonate precipitation resulting from the uptake of carbon by plants can rapidly reduce both free CO_2 and total carbon concentration in aquatic systems. Mixed plant populations whose constituent species have differing abilities to use the available carbon will be differentially stressed as pH rises during conditions where carbon

TABLE 9

Marl encrustations on macrophytes.

Species listed were collected in Loch Borralie, Sutherland which has an alkalinity of 2.4 m-equiv litre^{-1}.

	$\frac{\text{marl wt}}{\text{ash wt}} \times 100$
Hippuris vulgaris	7%
Potamogeton praelongus	30%
Myriophyllum spicatum	75%
Nitella sp.	80%
Chara sp.	92%

demand exceeds the supply. Under such conditions the plants behave as in a pH-drift experiment. Those species which rely almost entirely on free CO_2 will reach compensation point in water containing 2 m-equiv l^{-1} alkalinity when the pH rises to 9 - 9.5. At this alkalinity, even if enough CO_2 were added to lower the pH to 7.0, the concentration of free CO_2 and bicarbonate would still be insufficient to enable the macrophytes examined to photosynthesize at their full capacity, and any change in the pH of the bulk solution will affect the photosynthetic rate of these species.

An algal bloom of sufficient density to raise the pH of the water in the euphotic zone to 10 or so, will effectively cut off the carbon supply for most macrophytes and will, if persisting for long enough, cause their destruction. This will be in addition to the loss of light caused by the algal bloom.

Lakes with moderate alkalinity plus abundant phosphate and nitrogen characteristically have algal blooms in the summer with persistently high pH levels and tend to have macrophyte communities which are species poor. Such plants as *Fontinalis* and *Hippuris* rarely occur, although the latter might survive if it is able to become an emergent plant. These lakes in the author's experience do not have good growths of charophytes and those that do occur, are found in shallow water. Light reduction caused by the phytoplankton is possibly not the main factor causing the absence of charophytes and mosses as these plants can occur in very deep water with low light when other conditions are suitable.

While high pH levels may not actually lead to the disappearance of some species, the lack of sufficient carbon can result in a decrease in productivity. Few studies have been carried out to determine the effects of carbon depletion on the growth of macrophytes. Mulligan & Baranowski (1969) have shown that the productivity of *Myriophyllum spicatum* drops by 90% when in competition with algae which raised the pH of the bathing solution to 9.6. Because of the nature of the experiment several interpretations are possible, such as the reduction of light by the algae (light was lowered by 40%), competition for other nutrients and inhibitory substances.

The phytoplankton, composed of more ephemeral species, may react to progressive carbon depletion by undergoing a pattern of species succession (Talling 1976). Alteration of the species composition of the phytoplankton has been induced by carbon enrichment, alteration of pH or by creating greater carbon demand through the addition of nitrogen and phosphorus. Shapiro (1973) enriched the water contained in an enclosure in a lake by adding nitrate and phosphate. The pH rose from 9.8 to 10.7 and the phytoplankton remained predominantly composed of blue-green algae. When CO_2 gas or hydrochloric acid was added, lowering the pH to 5.5, green algae became the dominant group. Although the alkalinity of the water was not stated, the lake was in carbon deficit at the start of the experiment. Those species which were initially present would be those which were able to make use of the bicarbonate available and the addition of other nutrients simply increased their numbers. Shapiro felt that the rate of CO_2 supply was an important factor in determining the "qualitative nature of the phytoplankton" but he did not believe that "the rate of supply from natural sources in most cases, limits the gross production of phytoplankton". This statement is correct if the gross production is being carried out by species which can still photosynthesize when the free CO_2 supply has been depleted to the compensation point, but even these species will be showing some reduction in assimilation rate when the pH reaches 10. If depletion occurred rather suddenly (within a few days) so that the phytoplankton species composition did not have time to change, a significant reduction in productivity would occur.

The macrophyte community is not able to shift its species composition rapidly enough to cope with shortages of carbon brought about primarily through phytoplankton demands and gross productivity will fall. The macrophytes, being'weak users' of the bicarbonate component of the carbon supply means that they are at a severe disadvantage when in competition with a large phytoplankton population. Under such conditions an ability to "wait out" the period of carbon deficit while using stored carbohydrate will be required. In lakes where mixing is not too great, more carbon may be available near the bottom from decomposition in the sediments and some plants may be able to take up CO_2 through their roots (Wium-Andersen 1971).

Based on extensive field observations in Scotland and Western Canada and on surveys by Spence (1964), an hypothesis is proposed relating the carbonate system and nutrient status of lakes to their plant communities particularly the macrophytes. Three broad categories of lake can be defined on the basis of their carbonate system, each type having its own characteristic flora whose constituent species are not exposed to carbon depletion or are those species which can withstand some degree of depletion.

The first type are those of low alkalinity (less than 0.1 m-equiv l^{-1}) which have a low nutrient status and are usually classed as oligotrophic. They are found in drainage areas of hard or acidic rocks and their water may be very clear to darkly peat-stained. Floristically they are characterized by low phytoplankton densities and are sparsely populated with macrophytes. These tend to be slow-growing winter -green species such as *Lobelia dortmanna, Isoetes spp.*, and *Fontinalis* with the depth of colonization affected by the colour of the water (Light, 1973 and Spence, 1976). The pH of these waters is rarely above pH 7.5 and may be much lower, their free CO_2 concentration is at or above air-equilibrium. In these waters, levels of nitrogen or phosphorus limit plant production and the carbon reservoir, while quite small, is not taxed and atmospheric input is sufficient to supply demands. The plant communities in lakes of this type are easily altered by the addition of N and P which increase the productivity of the phytoplankton, and because of the low buffer capacity, the pH rises to very high values. Such an experiment has been described by Schindler *et al* (1973). The eutrophication of lake 227 in Manitoba which had an initial C_T concentration of 0.1 mM caused the pH to rise to about 10.

Such fertilization effectively converts such a lake to the second class - those with low to medium alkalinity (0.1 to 2 m-equiv l^{-1}) which, during the summer, incur some degree of carbon depletion. These meso to eutrophic lakes form the largest group and are the most difficult to define. Those which are the most eutrophic have a high overall primary productivity and have a high pH in summer, sometimes reaching 10 or more. Primary productivity, while high, is carried out by relatively few species.

Blue-green algae dominate the phytoplankton in summer and algal mats of *Cladophora*, *Rhizoclonium*, *Oedogonium* or *Spirogyra* may occur (Jupp & Spence 1977). Macrophytes typical of these lakes are *Potamogeton pectinatis*, *P. filiformis* and *Zannichellia palustris*. Even these may form only a sparse cover if algal densities are high. Light attenuation by the phytoplankton also limits macrophyte production and may restrict the depth colonized to less than 2 metres as in Loch Leven. Phosphate concentrations may still be significant and this may indicate that it is light and carbon which are limiting the growth of macrophytes rather than the other major nutrients.

The third type are those lakes which are of high alkalinity (over 2 m-equiv l^{-1}) which have a continuous input of inorganic carbon from limestone drainage areas. They are characterised by clear water, extensive marl deposits on the plants and in the sediments, and have free CO_2 concentrations near or slightly above air-equilibrium. Phytoplankton densities are low due possibly to phosphate removal by marl precipitation, hence the clarity of the water, although suspended calcium carbonate may cause cloudiness. The macrophyte community is often quite dense and is usually species rich. Because of the high buffer capacity of the carbonate system and the small demand for carbon from the phytoplankton, lakes of this type are rarely in carbon deficit. The equilibrium concentrations of CO_2^* in these lakes are sufficient to allow the growth of those species which do not use bicarbonate to a significant degree such as *Hippuris* and *Fontinalis*. The macrophytes in these lakes probably rely on the sediments for nutrients as these sediments typically have high ammonia and orthophosphate concentrations in the interstitial water (Allen, unpublished data).

Exceptions within these classifications can occur. Species like *Littorella uniflora*, while common in oligotrophic lakes can be found in mesotrophic lakes, at least in shallow waters, while charophytes may occur sparsely in quite eutrophic waters such as Loch Leven. In all cases, both the extent and duration of the summer carbon deficit is the important parameter in the lake classification. Brief and occasional phytoplankton blooms may cause a carbon deficit of short duration which will not, in the long term, affect the macrophyte species composition in the lake.

SUMMARY

A broad range of aquatic plants has been examined by means of three experimental techniques for the purpose of describing their abilities to use the different forms and concentrations of inorganic carbon which may be presented to them.

Experiments were carried out on macrophyte shoots or algal suspensions in a specially designed apparatus under uniform conditions of light (560 μEinsteins m^{-2} s^{-1}) and temperature (20°C) while measuring the rate of oxygen production, and the rate of carbon uptake as determined indirectly by pH measurements.

Kinetic experiments showed that macrophytes had more diffusive resistance to CO_{2*}^{*} uptake than microalgae; that microalgae had a high affinity for CO_2 and HCO_3^- whereas the macrophytes, including previously established bicarbonate users, had high affinities for CO_2^* only. The ratio of $[HCO_3^-]$ to $[CO_2^*]$ needed to produce the same rate of photosynthesis ranged from less than 1 in two of the microalgae to more than 100 in two macrophytes, implying a gradation in capability for bicarbonate use. Results of experiments at constant C_T with varied pH showed that, over the range 7.4 to 9.0, net photosynthesis of the macrophytes was primarily dependent upon $[CO_2^*]$ in a given C_T concentration but that of *Anabaena cylinrica* and *Chlorella emersonii* was not; their rates only became pH-dependent above pH 9.5. Bicarbonate use by macrophytes above pH 9 became apparent if the $[C_T]$ was high enough. The question of bicarbonate use by any species depends upon the concentration of bicarbonate in the bathing solution, that species' affinity for bicarbonate and its bicarbonate compensation point. Using the pH-drift technique, a method is described for distinguishing CO_2 and HCO_3^--compensation points. With this method, CO_2 compensation points were determined as 0.9 μM for *Cosmarium botrytis*, 4.5 μM for *Elodea canadensis*, 5.5 μM for *Eurhynchium rusciforme*, and 8 μM for *Fontinalis antipyretica*; HCO_3^--compensation points ranged from 0.05 mM in *Cosmarium* to, respectively, 0.9, 0.95, and 3.3 mM in the macrophytes.

From evidence from these three types of experiment, bicarbonate users and non-users do not exist as such but there is a graded capacity to use bicarbonate in which strong and weak users can be distinguished. Their poor affinity for bicarbonate means that most macrophytes can barely photosynthesise with this source at

natural alkalinities when pH rises above 9. Macrophytes are largely CO_2-dependent and, since CO_2^* is rarely saturating, they become pH-dependent. The photosynthetic activities of the plants in a lake, particularly those with a high affinity for bicarbonate can reduce the C_T concentration below the air-equilibrium level. The resulting rise in pH, and at times precipitation of marl, causes a severe reduction in the free CO_2 concentration which the weak users of bicarbonate rely on. It is suggested that competition for carbon arising from variations in alkalinity and from free CO_2 depletion constitute an important factor in determining the composition of the plant community in lakes, particularly the macrophytes, and these plants can serve as indicators of the long-term carbon status of a lake.

BIBLIOGRAPHY

Black, M.A. (1973). Exogenous inorganic carbon sources in photosynthesis of aquatic plants. Unpublished M.Sc. Thesis, University of St. Andrews.

Blackman, F.F., & Smith, A.M. (1911). On assimilation in submerged water plants and its relation to the concentration of carbon dioxide and other factors. Proc. Roy. Soc. Lond., B, 83, 389.

Borowitzka, M.A., & Larkum, A.W.D. (1976). Calcification in the green alga *Halimeda*. The sources of inorganic carbon for photosynthesis and calcification and a model of the mechanism of calcification. J. exp. Bot., 27, 879-93.

Briggs, G.E. & Whittingham, C.P. (1952). Factors affecting the rate of photosynthesis of *Chlorella* at low concentrations of carbon dioxide and in high illumination. New Phyt., 51, 236-49.

Broecker, W.S.,& Peng, T.-H. (1974). Gas exchange rate between air and sea. Tellus 26, 21-35.

Denny, P., & Weeks, D.C.(1970). Effects of light and bicarbonate on membrane potential in *Potamogeton Schweinfurthii* (Benn). Ann. Bot. 34, 483-96.

Dowd, J.E. & Riggs, D.S. (1965). A comparison of estimates of Michaelis-Menten kinetic constants from various linear transformations. J. biol. Chem. 240, 863-69.

Dryssen, D. (1965). A Gran titration of sea water on board Sagitta. Acta Chem. Scand. 19, 1265-68.

Emerson, S. (1975a). Chemically enhanced CO_2 gas exchange in a eutrophic lake: a general model. Limnol. Oceanogr. 20, 743-53.

Emerson, S. (1975b). Gas exchange rates in small Canadian Shield lakes. Limnol. Oceanogr. 20, 754-61.

Felföldy, L.J.M. (1962). On the role of pH and inorganic carbon sources in photosynthesis of unicellular algae. Acta biol. Acad. Sci. Hung. 13, 207-14.

Felföldy, L.J.M. (1965). Photosynthesis of the unicellular green algal strain *Scenedesmus obtusiusculus* (Chod.) at various pH values. Acta biol. Acad. Sci. Hung. 15, 351-59.

Fogg, G.E. & Than-Tun (1961). Interactions of photosynthesis and assimilation of elementary nitrogen in a blue-green alga. Proc. Roy. Soc. B. 153, 111-27.

Golterman,H.L. (1969). Methods for chemical analysis of fresh waters. Blackwell Scientific Publications, London.

Graham, D. & Reed, M.L. (1971). Carbonic anhydrase and the regulation of photosynthesis. Nature, London, 231NB, 81-83.

Gran, G. (1950). Determination of the equivalent point in potentiometric determinations. Acta Chem. Scand. 4, 559-577.

Harder, R. (1921). Kritische Versuche zu Blackman's Theorie begrenzenden Faktoren bei der Kohlensäureassimilation. J. Wiss. Bot. 60, 531

Hartman, R.T. & Brown, D.L. (1967). Changes in internal atmosphere of submersed vascular hydrophytes in relation to photosynthesis. Ecology, 48, 252-58.

Hassack, C. (1888). Ueber das Verhaltnis von Pflanzen zu Bicarbonaten und uber Kalkincrustation. Tubingen Bot. Inst. Unters., 2, 465-77.

Helquist, C.B. (1975). Correlation of selected dissolved substances and the distribution of *Potamogeton* in New England. Unpublished Ph.D. Thesis, University of New Hampshire.

Hill, R. & Whittingham, C.P. (1957). Photosynthesis. Methuen, London.

Iversen, J. (1929). Studien über die pH-Verhältnisse dänischer Gewässer und ihren Einflus auf die Hydrophyten-Vegetation. Bot. Tidskr., 40, 277-326.

Jupp, B.P. & Spence, D.H.N. (1977). Limitation on macrophytes in a eutrophic lake, Loch Leven. I Effects of phytoplankton. J. Ecol., 65, 175-186.

Kanwisher, J. (1963). Effect of wind on CO_2 exchange across the sea surface. J. Geophys. Res., 68, 3921-27.

Keenan, J.D. (1973). Response of *Anabaena* to pH, carbon, and phosphorus J. Environ. Engng. Div., Am. Soc. Civ. Engrs., 99, 607-20.

Kern, D.M. (1960). The hydration of carbon dioxide. J. chem. Educ., 37, 14-23.

Larson, T.E. & Buswell (1942). J. Amer. Water Works Assoc., 34, 1667- .

Light, J.J. (1975). Clear lakes and aquatic bryophytes in the mountains of Scotland. J. Ecol., 63, 937-943.

Lucas, W.J. (1975). Photosynthetic fixation of ^{14}carbon by internodal cells of *Chara corallina*. J. exp. Bot., 26, 331-46.

Lucas, W.J. & Smith, F.A. (1973). The formation of alkaline and acid regions on the surface of *Chara corallina* cells. J. exp. Bot., 24, 1-14.

Moyle, J.B. (1945). Some chemical factors influencing the distribution of aquatic plants in Minnesota. Amer. Midl. Nat., 34, 402-20.

Mulligan, H.F. & Baronowski (1969). Growth of phytoplankton and vascular aquatic plants at different nutrient levels. Verh. Internat. Verein. Limnol., 17, 802-10.

Österlind, S. (1951). Inorganic carbon sources of green algae. III. Measurements of photosynthesis in *Scenedesmus quadricauda* and *Chlorella pyrenoidosa*. Physiologia Pl., 4, 242-54.

Österlind, S. (1952). Inorganic carbon sources of green algae. IV. Further experiments concerning photo-activation of bicarbonate assimilation. Physiologia Pl., 5, 403-8.

Otsuki, A. & Wetzel, R.G. (1972). Coprecipitation of phosphate with carbonates in a marl lake. Limnol. Oceanogr., 17, 763-67.

Pasciak, W.J. & Gavis, J. (1975). Transport limited nutrient uptake rates in *Ditylum brightwellii*. Limnol. Oceanogr., 20, 604-17.

Peng, T.-H., Takahashi, T., & Broecker, W.S. (1974). Surface radon measurements in the North Pacific Ocean Station Papa. J. Geophys. Res., 79, 1772-80.

Rabinowitch, E. (1956). Photosynthesis and related processes. Vol. II Part 2. pp. 1886-1899. Interscience Publishers, New York.

Raven, J.A. (1968). The mechanism of photosynthetic use of HCO_3^- by *Hydrodictyon africanum*. J. exp. Bot., 19, 193-206.

Raven, J.A. (1970). Exogenous inorganic carbon sources in plant photosynthesis. Biol. Rev., 45, 167-221.

Ruttner, F. (1947). Zur Frage der Karbonatassimilation der Wasserpflanzen. I Teil: Die beiden Haupt-typen der Kohlenstoffaufnahme. Öst. bot. Z., 94, 265-94.

Ruttner, F. (1948). Zur Frage der Karbonatassimilation der Wasserpflanzen. II Teil: Das Verhalten von *Elodea canadensis* und *Fontinalis antipyretica* in Losungen von Natrium-bzw. Kaliumbikarbonat. Ost. bot. Z., 95, 208-38.

Schelske, C.L. (1962). Iron, organic matter, and other factors limiting primary productivity in a marl lake. Science, 136, 45-46.

Schindler, D.W.(1975). Factors affecting gas exchange in natural waters. Limnol. Oceanogr., 20, 1053-54.

Schindler, D.W.; Kling, H.J., Schmidt, R.V., Prokopowich, J., Frost, V.E., Reid, R.A. & Capel, M., (1973). Eutrophication of Lake 227, Experimental Lakes Area, northwestern Ontario, by addition of phosphate and nitrate., J. Fish. Res. Board Can. 30, 1415-40.

Shapiro, J. (1973). Blue-green algae: Why they become dominant. Science, 179, 382-383.

Smith, F.A. (1968). Rates of photosynthesis in characean cells. Photosynthetic $^{14}CO_2$ fixation and ^{14}C-bicarbonate uptake by characean cells. J. exp. Bot., 19, 207-17.

Smith, F.A. (1970). The mechanism of chloride transport in Characean cells. New Phytol., 69, 903-17.

Spence, D.H.N. (1964). The macrophytic vegetation of freshwater lochs, swamps and associated fens. In: The vegetation of Scotland (Ed. by J.H. Burnett). pp. 306-425. Oliver and Boyd, Edinburgh.

Spence, D.H.N. (1967). Factors controlling the distribution of freshwater macrophytes, with particular reference to Scottish lochs. J. Ecol., 55, 147-70.

Spence, D.H.N. (1976). Light and plant response in freshwater. In: Light as an ecological factor II (Ed. by R. Bainbridge, G.C. Evans and O. Rackham), pp. 93-133. Blackwell Scientific Publications, Oxford.

Steemann Nielsen, E. (1947). Photosynthesis of aquatic plants with special reference to the carbon sources. Dansk. Bot. Ark., 12, 1-71.

Steemann Nielsen, E. & Jensen, P.K. (1958). Concentrations of carbon dioxide and rate of photosynthesis in *Chlorella pyrenoidosa*. Physiol. Plant., 11, 170-80.

Stumm, W. & Morgan, J.J. (1970). Aquatic Chemistry. Wiley-Interscience, New York.

Talling, J.F. (1973). The application of some electrochemical methods to the measurement of photosynthesis and respiration in fresh waters. Freshwat. Biol., 3, 335-62.

Talling, J.F. (1976). The depletion of carbon dioxide from lake water by phytoplankton. J. Ecol., 64, 79-121.

Thurber, D.L. & Broecker, W.S. (1970). The behavior of radiocarbon in the surface waters of the Great Basin. Nobel Symp., 12, 397-400.

Tregunna, E.B. & Thomas, E.A. (1968). Measurement of inorganic carbon and photosynthesis in seawater by pCO_2 and pH analysis. Can. J. Bot., 46, 481-85.

Wetzel, R.G. (1975). Limnology. W.B. Saunders, Philadelphia. 743pp.

Wium-Andersen, S. (1971). Photosynthetic uptake of free CO_2 by the roots of *Lobelia dortmanna*. Physiol. Plant., 25, 245-48.

Wood, R.D. & Imahori, K. (1965). A revision of the Characeae. Cramer, Weinheim. 904pp.

APPENDIX I

Solubility of CO_2 in water in equilibrium with the gas phase.

The amount of carbon dioxide dissolving in pure water in equilibrium with pure CO_2 gas is

$$mM\ CO_2\ ml^{-1} = \frac{(B_m - vp)\ K_H}{B_s}$$

where B_m is the observed barometric pressure (mm Hg)
B_s is the standard barometric pressure (760 mm Hg)
vp is the vapour pressure of water (mm Hg)
K_H is Henry's law constant = CO_2^*/pCO_2 ($M\ atm^{-1}$)

Temp °C	K_H	vp
0	0.0764	4.579
1	0.0734	4.926
2	0.0707	5.294
5	0.0635	6.543
10	0.0533	9.209
15	0.0455	12.788
16	0.0439	13.634
17	0.0427	14.530
18	0.0414	15.477
19	0.0402	16.477
20	0.0392	17.535
21	0.0381	18.650
22	0.0370	19.827
23	0.0359	21.068
24	0.0348	22.377
25	0.0339	23.756

Appendix II

Procedure for the Gran titration.

Samples should be handled as little as possible to minimize CO_2 exchange with the air. Field samples may be collected in 50 or 100 ml conical flasks with ground-glass stoppers. Using magnetic stirring, the water sample is titrated by adding increments of HCl of known strength. Titrations are done with a micro-burette, or better, with a syringe-type burette holding 0.5 ml. With the latter, an acid strength of 0.2 to 0.5 normal in convenient.

Procedure.

Add several increments of acid, reading the pH after each addition to 0.01 unit after allowing the reading to stabilise. The readings should be within the range 7.6 to 6.7. Acid is then added to lower the pH to 4.4 when a second series of increments is added until pH 3.7 is reached. The volumes recorded after each increment is the total of all increments.

The absolute calibration of the pH meter is not too important as the titration calculations are based on the relative changes in pH during the step-wise titration.

Calculations.

(a) Use each pH reading and volume in the acid range to calculate the function F_2.

$$F_2 = \text{antilog}(a-pH) \times (Vs + v)$$

a = any convenient number such as 5 (should be close to the upper pH)

Vs = sample volume (ml)

v = titrant volume (ml)

The term $(Vs + v)$ corrects for dilution of the sample by the titrant. Plot F_2 against v and fit a straight line to the points. A good titration should give a very straight plot. Locate the intersection of the plot v_2 on the v axis.

(b) Use each pH reading and volume in the higher range to calculate the function F_1.

$$F_1 = \text{antilog}(b-pH)\ (V_s + v)\ (v_2 - v)$$

b = any number such as 8

The term $(v_2 - v)$ allows for decreasing alkalinity during the titration.

Plot F_1 against v and fit the best straight line through the points and locate its intersection (v_1) on the v axis.

The intersections v_1 and v_2 represent the endpoints of the titration. They are converted to the sample concentrations V_1 and V_2 by the expressions:

$$V_1 \text{ (m-equiv } l^{-1}) = v_1 \frac{1000}{V_s} \cdot n$$

$$V_2 \underset{\text{(m-equiv } l^{-1})}{\text{ (total alkalinity)}} = v_2 \frac{1000}{V_s} n$$

$$C_T \underset{\text{(mM)}}{\text{ (total carbon)}} = V_2 - V_1 = \frac{1000}{V_s} n$$

where n is the normality of the titrant.

With slight modifications, the Gran titration will also give the $[H^+]$ of the sample. The method given is adapted from Dryssen (1965).

While performing the usual steps of the Gran titration, the potential of the electrode is measured in millivolts at the beginning of the titration as well as pH. Near the end of the titration when the pH has fallen to about 4, both millivolts and pH are measured after each addition of acid to about pH 3.5

Calculations:

$$[H^+] \underset{\text{of acid)}}{\text{(after each addition}} = \frac{(v - v_2)}{V_s + v}$$

Using the value of $[H^+]$ the standard potential of the electrode E_o is

$$E_o = E + (58.17 \log[H^+])$$

where E is the measured potential in millivolts, and 58.17 mv is derived from the gas constant and is temperature dependent. E_o is taken as the mean of several measurements in the titration. From the value of E_o, the same equation may be used to determine the $[H^+]$ of the sample, where in this case, the value of E used is the electrode potential of the unacidified sample.

$$[H^+] = \frac{E_o - E}{58.17}$$

Normally, the pH of the solution is found by calibrating the electrode and meter assembly with a standard buffer and this may not always be accurate under the conditions of measurement. The presence of other solutes may lower the activity factor and the activity of $[H^+]$ may be less than that indicated by pH.

Temperature (^{o}C)	$\frac{2.3026\ RT}{F}$ (millivolts)
0	54.20
4	54.99
10	56.18
15	57.17
16	57.37
17	57.57
18	57.77
19	57.97
20	58.17
21	58.36
22	58.56
23	58.76
24	58.96
25	59.16

APPENDIX III

Components of the carbonate system.

Tables are based on six alkalinity concentrations (0.1, 0.5, 1.0, 2.0, 4.0, 10.0 m-equiv l^{-1}). For each alkalinity, values of the ionization fractions; α_0, α_1, and α_2 at 20°C are given for a range of pH values and are calculated from equations (1) to (3) in Part I. The ionization constants used have been corrected for the effect of total solute concentration when the solutions are made with $KHCO_3$.

In the second row, C_T and its product with each of the ionization fractions (CO_2, HCO_3^- and CO_3^{2-}) is given. All numbers are expressed in exponential form. ALPHA 3= $\alpha_1 + 2\alpha_2$.

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.5000E 01	0.9601E 00	0.3993E-01	0.1676E-06	0.3993E-01
0.2504E 01	0.2404E 01	0.1000E 00	0.4198E-06		
0.1000E-03	0.5100E 01	0.9502E 00	0.4975E-01	0.2629E-06	0.4976E-01
0.2010E 01	0.1910E 01	0.1000E 00	0.5284E-06		
0.1000E-03	0.5200E 01	0.9382E 00	0.6184E-01	0.4114E-06	0.6184E-01
0.1617E 01	0.1517E 01	0.1000E 00	0.6653E-06		
0.1000E-03	0.5300E 01	0.9234E 00	0.7663E-01	0.6418E-06	0.7663E-01
0.1305E 01	0.1205E 01	0.1000E 00	0.8375E-06		
0.1000E-03	0.5400E 01	0.9054E 00	0.9459E-01	0.9973E-06	0.9459E-01
0.1057E 01	0.9572E 00	0.1000E 00	0.1054E-05		
0.1000E-03	0.5500E 01	0.8838E 00	0.1162E 00	0.1543E-05	0.1162E 00
0.8603E 00	0.7603E 00	0.1000E 00	0.1327E-05		
0.1000E-03	0.5600E 01	0.8579E 00	0.1421E 00	0.2374E-05	0.1421E 00
0.7039E 00	0.6039E 00	0.9999E-01	0.1671E-05		
0.1000E-03	0.5700E 01	0.8275E 00	0.1725E 00	0.3629E-05	0.1725E 00
0.5797E 00	0.4797E 00	0.9999E-01	0.2104E-05		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.5800E 01	0.7921E 00	0.2079E 00	0.5505E-05	0.2079E 00
0.4810E 00	0.3810E 00	0.9999E-01	0.2648E-05		
0.1000E-03	0.5900E 01	0.7517E 00	0.2483E 00	0.8280E-05	0.2483E 00
0.4026E 00	0.3027E 00	0.9999E-01	0.3334E-05		
0.1000E-03	0.6000E 01	0.7063E 00	0.2937E 00	0.1233E-04	0.2938E 00
0.3404E 00	0.2404E 00	0.9998E-01	0.4197E-05		
0.1000E-03	0.6100E 01	0.6563E 00	0.3437E 00	0.1816E-04	0.3437E 00
0.2909E 00	0.1910E 00	0.9998E-01	0.5283E-05		
0.1000E-03	0.6200E 01	0.6027E 00	0.3973E 00	0.2643E-04	0.3973E 00
0.2517E 00	0.1517E 00	0.9998E-01	0.6651E-05		
0.1000E-03	0.6300E 01	0.5465E 00	0.4535E 00	0.3798E-04	0.4536E 00
0.2204E 00	0.1205E 00	0.9997E-01	0.8373E-05		
0.1000E-03	0.6400E 01	0.4890E 00	0.5109E 00	0.5387E-04	0.5110E 00
0.1957E 00	0.9568E-01	0.9996E-01	0.1054E-04		
0.1000E-03	0.6500E 01	0.4319E 00	0.5680E 00	0.7540E-04	0.5682E 00
0.1760E 00	0.7600E-01	0.9995E-01	0.1327E-04		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.6600E 01	0.3765E 00	0.6234E 00	0.1042E-03	0.6236E 00
0.1603E 00	0.6036E-01	0.9994E-01	0.1670E-04		
0.1000E-03	0.6700E 01	0.3242E 00	0.6757E 00	0.1421E-03	0.6760E 00
0.1479E 00	0.4794E-01	0.9992E-01	0.2102E-04		
0.1000E-03	0.6800E 01	0.2759E 00	0.7239E 00	0.1917E-03	0.7243E 00
0.1380E 00	0.3807E-01	0.9990E-01	0.2646E-04		
0.1000E-03	0.6900E 01	0.2323E 00	0.7674E 00	0.2559E-03	0.7680E 00
0.1301E 00	0.3023E-01	0.9988E-01	0.3330E-04		
0.1000E-03	0.7000E 01	0.1938E 00	0.8059E 00	0.3383E-03	0.8066E 00
0.1239E 00	0.2401E-01	0.9985E-01	0.4191E-04		
0.1000E-03	0.7100E 01	0.1603E 00	0.8393E 00	0.4435E-03	0.8402E 00
0.1189E 00	0.1906E-01	0.9981E-01	0.5274E-04		
0.1000E-03	0.7200E 01	0.1316E 00	0.8678E 00	0.5773E-03	0.8689E 00
0.1150E 00	0.1513E-01	0.9976E-01	0.6637E-04		
0.1000E-03	0.7300E 01	0.1075E 00	0.8918E 00	0.7469E-03	0.8933E 00
0.1118E 00	0.1201E-01	0.9970E-01	0.8350E-04		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.7400E 01	0.8728E-01	0.9118E 00	0.9613E-03	0.9137E 00
0.1093E 00	0.9536E-02	0.9962E-01	0.1050E-03		
0.1000E-03	0.7500E 01	0.7058E-01	0.9282E 00	0.1232E-02	0.9307E 00
0.1072E 00	0.7567E-02	0.9952E-01	0.1321E-03		
0.1000E-03	0.7600E 01	0.5687E-01	0.9416E 00	0.1573E-02	0.9447E 00
0.1056E 00	0.6003E-02	0.9940E-01	0.1661E-03		
0.1000E-03	0.7700E 01	0.4569E-01	0.9523E 00	0.2003E-02	0.9563E 00
0.1042E 00	0.4761E-02	0.9924E-01	0.2088E-03		
0.1000E-03	0.7800E 01	0.3662E-01	0.9608E 00	0.2545E-02	0.9659E 00
0.1031E 00	0.3774E-02	0.9905E-01	0.2623E-03		
0.1000E-03	0.7900E 01	0.2929E-01	0.9675E 00	0.3226E-02	0.9739E 00
0.1021E 00	0.2991E-02	0.9880E-01	0.3294E-03		
0.1000E-03	0.8000E 01	0.2338E-01	0.9725E 00	0.4082E-02	0.9807E 00
0.1013E 00	0.2368E-02	0.9849E-01	0.4134E-03		
0.1000E-03	0.8100E 01	0.1864E-01	0.9762E 00	0.5158E-02	0.9865E 00
0.1005E 00	0.1874E-02	0.9811E-01	0.5184E-03		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.8200E 01	0.1485E-01	0.9786E 00	0.6510E-02	0.9917E 00
0.9975E-01	0.1481E-02	0.9762E-01	0.6494E-03		
0.1000E-03	0.8300E 01	0.1181E-01	0.9800E 00	0.8207E-02	0.9964E 00
0.9900E-01	0.1169E-02	0.9702E-01	0.8125E-03		
0.1000E-03	0.8400E 01	0.9384E-02	0.9803E 00	0.1034E-01	0.1001E 01
0.9820E-01	0.9214E-03	0.9626E-01	0.1015E-02		
0.1000E-03	0.8500E 01	0.7448E-02	0.9796E 00	0.1300E-01	0.1006E 01
0.9731E-01	0.7248E-03	0.9532E-01	0.1265E-02		
0.1000E-03	0.8600E 01	0.5905E-02	0.9778E 00	0.1634E-01	0.1010E 01
0.9629E-01	0.5686E-03	0.9414E-01	0.1573E-02		
0.1000E-03	0.8700E 01	0.4677E-02	0.9748E 00	0.2051E-01	0.1016E 01
0.9508E-01	0.4447E-03	0.9269E-01	0.1950E-02		
0.1000E-03	0.8800E 01	0.3699E-02	0.9706E 00	0.2570E-01	0.1022E 01
0.9364E-01	0.3464E-03	0.9089E-01	0.2407E-02		
0.1000E-03	0.8900E 01	0.2921E-02	0.9649E 00	0.3217E-01	0.1029E 01
0.9190E-01	0.2684E-03	0.8868E-01	0.2957E-02		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.9000E 01	0.2302E-02	0.9575E 00	0.4019E-01	0.1038E 01
0.8979E-01	0.2067E-03	0.8598E-01	0.3609E-02		
0.1000E-03	0.9100E 01	0.1811E-02	0.9481E 00	0.5010E-01	0.1048E 01
0.8722E-01	0.1579E-03	0.8269E-01	0.4370E-02		
0.1000E-03	0.9200E 01	0.1420E-02	0.9363E 00	0.6229E-01	0.1061E 01
0.8409E-01	0.1195E-03	0.7874E-01	0.5238E-02		
0.1000E-03	0.9300E 01	0.1111E-02	0.9217E 00	0.7719E-01	0.1076E 01
0.8031E-01	0.8920E-04	0.7402E-01	0.6199E-02		
0.1000E-03	0.9400E 01	0.8652E-03	0.9038E 00	0.9529E-01	0.1094E 01
0.7575E-01	0.6554E-04	0.6846E-01	0.7218E-02		
0.1000E-03	0.9500E 01	0.6708E-03	0.8822E 00	0.1171E 00	0.1116E 01
0.7029E-01	0.4715E-04	0.6201E-01	0.8231E-02		
0.1000E-03	0.9600E 01	0.5172E-03	0.8564E 00	0.1431E 00	0.1143E 01
0.6380E-01	0.3300E-04	0.5464E-01	0.9130E-02		
0.1000E-03	0.9700E 01	0.3962E-03	0.8259E 00	0.1737E 00	0.1173E 01
0.5615E-01	0.2225E-04	0.4637E-01	0.9755E-02		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-03	0.9800E 01	0.3012E-03	0.7904E 00	0.2093E 00	0.1209E 01
0.4719E-01	0.1421E-04	0.3730E-01	0.9877E-02		
0.1000E-03	0.9900E 01	0.2270E-03	0.7498E 00	0.2500E 00	0.1250E 01
0.3675E-01	0.8341E-05	0.2755E-01	0.9187E-02		
0.1000E-03	0.1000E 02	0.1693E-03	0.7042E 00	0.2956E 00	0.1295E 01
0.2465E-01	0.4174E-05	0.1736E-01	0.7285E-02		
0.5000E-03	0.6000E 01	0.6981E 00	0.3019E 00	0.1479E-04	0.3020E 00
0.1656E 01	0.1156E 01	0.4999E 00	0.2449E-04		
0.5000E-03	0.6100E 01	0.6474E 00	0.3525E 00	0.2174E-04	0.3526E 00
0.1418E 01	0.9181E 00	0.4999E 00	0.3083E-04		
0.5000E-03	0.6200E 01	0.5933E 00	0.4067E 00	0.3157E-04	0.4068E 00
0.1229E 01	0.7293E 00	0.4999E 00	0.3881E-04		
0.5000E-03	0.6300E 01	0.5368E 00	0.4632E 00	0.4527E-04	0.4633E 00
0.1079E 01	0.5793E 00	0.4999E 00	0.4885E-04		
0.5000E-03	0.6400E 01	0.4793E 00	0.5207E 00	0.6406E-04	0.5208E 00
0.9600E 00	0.4601E 00	0.4999E 00	0.6150E-04		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.6500E 01	0.4223E 00	0.5776E 00	0.8946E-04	0.5778E 00
0.8653E 00	0.3654E 00	0.4998E 00	0.7741E-04		
0.5000E-03	0.6600E 01	0.3674E 00	0.6325E 00	0.1233E-03	0.6328E 00
0.7901E 00	0.2903E 00	0.4998E 00	0.9745E-04		
0.5000E-03	0.6700E 01	0.3156E 00	0.6842E 00	0.1680E-03	0.6845E 00
0.7304E 00	0.2305E 00	0.4997E 00	0.1227E-03		
0.5000E-03	0.6800E 01	0.2681E 00	0.7317E 00	0.2261E-03	0.7321E 00
0.6829E 00	0.1831E 00	0.4996E 00	0.1544E-03		
0.5000E-03	0.6900E 01	0.2254E 00	0.7743E 00	0.3012E-03	0.7749E 00
0.6452E 00	0.1454E 00	0.4996E 00	0.1943E-03		
0.5000E-03	0.7000E 01	0.1877E 00	0.8119E 00	0.3976E-03	0.8127E 00
0.6152E 00	0.1155E 00	0.4994E 00	0.2446E-03		
0.5000E-03	0.7100E 01	0.1551E 00	0.8444E 00	0.5206E-03	0.8454E 00
0.5913E 00	0.9170E-01	0.4993E 00	0.3079E-03		
0.5000E-03	0.7200E 01	0.1272E 00	0.8721E 00	0.6770E-03	0.8735E 00
0.5723E 00	0.7281E-01	0.4991E 00	0.3874E-03		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.7300E 01	0.1038E 00	0.8954E 00	0.8750E-03	0.8971E 00
0.5572E 00	0.5781E-01	0.4989E 00	0.4875E-03		
0.5000E-03	0.7400E 01	0.8419E-01	0.9147E 00	0.1125E-02	0.9169E 00
0.5451E 00	0.4589E-01	0.4986E 00	0.6134E-03		
0.5000E-03	0.7500E 01	0.6804E-01	0.9305E 00	0.1441E-02	0.9334E 00
0.5354E 00	0.3643E-01	0.4982E 00	0.7717E-03		
0.5000E-03	0.7600E 01	0.5479E-01	0.9434E 00	0.1839E-02	0.9471E 00
0.5277E 00	0.2891E-01	0.4978E 00	0.9706E-03		
0.5000E-03	0.7700E 01	0.4400E-01	0.9537E 00	0.2341E-02	0.9583E 00
0.5214E 00	0.2294E-01	0.4972E 00	0.1221E-02		
0.5000E-03	0.7800E 01	0.3524E-01	0.9618E 00	0.2972E-02	0.9677E 00
0.5162E 00	0.1819E-01	0.4965E 00	0.1534E-02		
0.5000E-03	0.7900E 01	0.2818E-01	0.9681E 00	0.3766E-02	0.9756E 00
0.5120E 00	0.1443E-01	0.4956E 00	0.1928E-02		
0.5000E-03	0.8000E 01	0.2249E-01	0.9727E 00	0.4764E-02	0.9823E 00
0.5083E 00	0.1143E-01	0.4945E 00	0.2422E-02		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.8100E 01	0.1793E-01	0.9761E 00	0.6018E-02	0.9881E 00
0.5052E 00	0.9056E-02	0.4931E 00	0.3040E-02		
0.5000E-03	0.8200E 01	0.1427E-01	0.9781E 00	0.7593E-02	0.9933E 00
0.5023E 00	0.7167E-02	0.4913E 00	0.3814E-02		
0.5000E-03	0.8300E 01	0.1135E-01	0.9791E 00	0.9568E-02	0.9982E 00
0.4995E 00	0.5668E-02	0.4891E 00	0.4779E-02		
0.5000E-03	0.8400E 01	0.9011E-02	0.9789E 00	0.1204E-01	0.1003E 01
0.4968E 00	0.4477E-02	0.4863E 00	0.5983E-02		
0.5000E-03	0.8500E 01	0.7149E-02	0.9777E 00	0.1514E-01	0.1008E 01
0.4939E 00	0.3531E-02	0.4829E 00	0.7479E-02		
0.5000E-03	0.8600E 01	0.5664E-02	0.9753E 00	0.1902E-01	0.1013E 01
0.4907E 00	0.2780E-02	0.4786E 00	0.9332E-02		
0.5000E-03	0.8700E 01	0.4483E-02	0.9717E 00	0.2385E-01	0.1019E 01
0.4872E 00	0.2184E-02	0.4733E 00	0.1162E-01		
0.5000E-03	0.8800E 01	0.3542E-02	0.9666E 00	0.2987E-01	0.1026E 01
0.4830E 00	0.1711E-02	0.4669E 00	0.1443E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.8900E 01	0.2794E-02	0.9599E 00	0.3734E-01	0.1035E 01
0.4781E 00	0.1336E-02	0.4589E 00	0.1785E-01		
0.5000E-03	0.9000E 01	0.2199E-02	0.9512E 00	0.4659E-01	0.1044E 01
0.4722E 00	0.1039E-02	0.4492E 00	0.2200E-01		
0.5000E-03	0.9100E 01	0.1727E-02	0.9403E 00	0.5798E-01	0.1056E 01
0.4653E 00	0.8035E-03	0.4375E 00	0.2697E-01		
0.5000E-03	0.9200E 01	0.1352E-02	0.9267E 00	0.7193E-01	0.1071E 01
0.4570E 00	0.6178E-03	0.4235E 00	0.3287E-01		
0.5000E-03	0.9300E 01	0.1055E-02	0.9100E 00	0.8893E-01	0.1088E 01
0.4471E 00	0.4715E-03	0.4069E 00	0.3976E-01		
0.5000E-03	0.9400E 01	0.8190E-03	0.8897E 00	0.1095E 00	0.1109E 01
0.4356E 00	0.3567E-03	0.3875E 00	0.4768E-01		
0.5000E-03	0.9500E 01	0.6327E-03	0.8653E 00	0.1340E 00	0.1133E 01
0.4222E 00	0.2671E-03	0.3653E 00	0.5658E-01		
0.5000E-03	0.9600E 01	0.4858E-03	0.8364E 00	0.1631E 00	0.1163E 01
0.4068E 00	0.1976E-03	0.3402E 00	0.6634E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.9700E 01	0.3703E-03	0.8026E 00	0.1970E 00	0.1197E 01
0.3893E 00	0.1442E-03	0.3125E 00	0.7670E-01		
0.5000E-03	0.9800E 01	0.2799E-03	0.7637E 00	0.2360E 00	0.1236E 01
0.3699E 00	0.1035E-03	0.2825E 00	0.8729E-01		
0.5000E-03	0.9900E 01	0.2095E-03	0.7198E 00	0.2800E 00	0.1280E 01
0.3484E 00	0.7300E-04	0.2508E 00	0.9757E-01		
0.5000E-03	0.1000E 02	0.1552E-03	0.6711E 00	0.3287E 00	0.1329E 01
0.3251E 00	0.5045E-04	0.2182E 00	0.1069E 00		
0.5000E-03	0.1002E 02	0.1459E-03	0.6609E 00	0.3390E 00	0.1339E 01
0.3202E 00	0.4673E-04	0.2116E 00	0.1085E 00		
0.5000E-03	0.1004E 02	0.1372E-03	0.6505E 00	0.3493E 00	0.1349E 01
0.3153E 00	0.4324E-04	0.2051E 00	0.1101E 00		
0.5000E-03	0.1006E 02	0.1289E-03	0.6400E 00	0.3599E 00	0.1360E 01
0.3102E 00	0.3998E-04	0.1985E 00	0.1116E 00		
0.5000E-03	0.1008E 02	0.1210E-03	0.6293E 00	0.3706E 00	0.1370E 01
0.3051E 00	0.3693E-04	0.1920E 00	0.1131E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.1010E 02	0.1136E-03	0.6185E 00	0.3814E 00	0.1381E 01
0.2999E 00	0.3407E-04	0.1855E 00	0.1144E 00		
0.5000E-03	0.1012E 02	0.1066E-03	0.6076E 00	0.3923E 00	0.1392E 01
0.2947E 00	0.3140E-04	0.1790E 00	0.1156E 00		
0.5000E-03	0.1014E 02	0.9992E-04	0.5966E 00	0.4033E 00	0.1403E 01
0.2894E 00	0.2891E-04	0.1726E 00	0.1167E 00		
0.5000E-03	0.1016E 02	0.9365E-04	0.5854E 00	0.4145E 00	0.1414E 01
0.2839E 00	0.2659E-04	0.1662E 00	0.1177E 00		
0.5000E-03	0.1018E 02	0.8772E-04	0.5742E 00	0.4257E 00	0.1426E 01
0.2785E 00	0.2443E-04	0.1599E 00	0.1185E 00		
0.5000E-03	0.1020E 02	0.8212E-04	0.5629E 00	0.4370E 00	0.1437E 01
0.2729E 00	0.2241E-04	0.1536E 00	0.1192E 00		
0.5000E-03	0.1022E 02	0.7685E-04	0.5516E 00	0.4483E 00	0.1448E 01
0.2672E 00	0.2054E-04	0.1474E 00	0.1198E 00		
0.5000E-03	0.1024E 02	0.7187E-04	0.5402E 00	0.4598E 00	0.1460E 01
0.2615E 00	0.1879E-04	0.1413E 00	0.1202E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.1026E 02	0.6718E-04	0.5287E 00	0.4712E 00	0.1471E 01
0.2557E 00	0.1718E-04	0.1352E 00	0.1205E 00		
0.5000E-03	0.1028E 02	0.6276E-04	0.5172E 00	0.4827E 00	0.1483E 01
0.2497E 00	0.1567E-04	0.1292E 00	0.1206E 00		
0.5000E-03	0.1030E 02	0.5860E-04	0.5057E 00	0.4942E 00	0.1494E 01
0.2437E 00	0.1428E-04	0.1233E 00	0.1205E 00		
0.5000E-03	0.1032E 02	0.5469E-04	0.4942E 00	0.5057E 00	0.1506E 01
0.2376E 00	0.1300E-04	0.1174E 00	0.1202E 00		
0.5000E-03	0.1034E 02	0.5102E-04	0.4827E 00	0.5172E 00	0.1517E 01
0.2314E 00	0.1180E-04	0.1117E 00	0.1197E 00		
0.5000E-03	0.1036E 02	0.4756E-04	0.4712E 00	0.5287E 00	0.1529E 01
0.2251E 00	0.1070E-04	0.1061E 00	0.1190E 00		
0.5000E-03	0.1038E 02	0.4432E-04	0.4598E 00	0.5402E 00	0.1540E 01
0.2186E 00	0.9688E-05	0.1005E 00	0.1181E 00		
0.5000E-03	0.1040E 02	0.4127E-04	0.4484E 00	0.5516E 00	0.1552E 01
0.2120E 00	0.8751E-05	0.9507E-01	0.1170E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.1042E 02	0.3842E-04	0.4370E 00	0.5630E 00	0.1563E 01
0.2053E 00	0.7889E-05	0.8974E-01	0.1156E 00		
0.5000E-03	0.1044E 02	0.3574E-04	0.4257E 00	0.5743E 00	0.1574E 01
0.1985E 00	0.7094E-05	0.8451E-01	0.1140E 00		
0.5000E-03	0.1046E 02	0.3323E-04	0.4145E 00	0.5855E 00	0.1585E 01
0.1915E 00	0.6365E-05	0.7939E-01	0.1121E 00		
0.5000E-03	0.1048E 02	0.3088E-04	0.4034E 00	0.5966E 00	0.1597E 01
0.1844E 00	0.5695E-05	0.7438E-01	0.1100E 00		
0.5000E-03	0.1050E 02	0.2869E-04	0.3923E 00	0.6076E 00	0.1608E 01
0.1771E 00	0.5081E-05	0.6949E-01	0.1076E 00		
0.5000E-03	0.1052E 02	0.2663E-04	0.3814E 00	0.6186E 00	0.1619E 01
0.1696E 00	0.4518E-05	0.6471E-01	0.1049E 00		
0.5000E-03	0.1054E 02	0.2471E-04	0.3706E 00	0.6294E 00	0.1629E 01
0.1620E 00	0.4004E-05	0.6004E-01	0.1020E 00		
0.5000E-03	0.1056E 02	0.2292E-04	0.3599E 00	0.6400E 00	0.1640E 01
0.1542E 00	0.3534E-05	0.5549E-01	0.9867E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.5000E-03	0.1058E 02	0.2125E-04	0.3494E 00	0.6506E 00	0.1651E 01
0.1461E 00	0.3105E-05	0.5105E-01	0.9507E-01		
0.5000E-03	0.1060E 02	0.1969E-04	0.3390E 00	0.6610E 00	0.1661E 01
0.1379E 00	0.2714E-05	0.4674E-01	0.9113E-01		
0.5000E-03	0.1062E 02	0.1823E-04	0.3288E 00	0.6712E 00	0.1671E 01
0.1294E 00	0.2359E-05	0.4253E-01	0.8684E-01		
0.5000E-03	0.1064E 02	0.1688E-04	0.3187E 00	0.6813E 00	0.1681E 01
0.1206E 00	0.2037E-05	0.3845E-01	0.8220E-01		
0.5000E-03	0.1066E 02	0.1562E-04	0.3088E 00	0.6912E 00	0.1691E 01
0.1117E 00	0.1744E-05	0.3448E-01	0.7718E-01		
0.5000E-03	0.1068E 02	0.1445E-04	0.2990E 00	0.7010E 00	0.1701E 01
0.1024E 00	0.1479E-05	0.3062E-01	0.7178E-01		
0.5000E-03	0.1070E 02	0.1335E-04	0.2895E 00	0.7105E 00	0.1711E 01
0.9285E-01	0.1240E-05	0.2688E-01	0.6597E-01		
0.1000E-02	0.6000E 01	0.6951E 00	0.3048E 00	0.1585E-04	0.3049E 00
0.3280E 01	0.2280E 01	0.9999E 00	0.5199E-04		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.6100E 01	0.6443E 00	0.3557E 00	0.2329E-04	0.3557E 00
0.2811E 01	0.1811E 01	0.9999E 00	0.6545E-04		
0.1000E-02	0.6200E 01	0.5899E 00	0.4100E 00	0.3379E-04	0.4101E 00
0.2438E 01	0.1439E 01	0.9998E 00	0.8240E-04		
0.1000E-02	0.6300E 01	0.5333E 00	0.4666E 00	0.4842E-04	0.4667E 00
0.2143E 01	0.1143E 01	0.9998E 00	0.1037E-03		
0.1000E-02	0.6400E 01	0.4758E 00	0.5241E 00	0.6846E-04	0.5243E 00
0.1907E 01	0.9076E 00	0.9997E 00	0.1306E-03		
0.1000E-02	0.6500E 01	0.4189E 00	0.5810E 00	0.9553E-04	0.5812E 00
0.1721E 01	0.7209E 00	0.9996E 00	0.1644E-03		
0.1000E-02	0.6600E 01	0.3641E 00	0.6357E 00	0.1316E-03	0.6360E 00
0.1572E 01	0.5725E 00	0.9996E 00	0.2069E-03		
0.1000E-02	0.6700E 01	0.3127E 00	0.6872E 00	0.1791E-03	0.6875E 00
0.1454E 01	0.4547E 00	0.9994E 00	0.2605E-03		
0.1000E-02	0.6800E 01	0.2654E 00	0.7344E 00	0.2409E-03	0.7348E 00
0.1361E 01	0.3612E 00	0.9993E 00	0.3279E-03		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.6900E 01	0.2230E 00	0.7767E 00	0.3208E-03	0.7773E 00
0.1286E 01	0.2868E 00	0.9991E 00	0.4127E-03		
0.1000E-02	0.7000E 01	0.1856E 00	0.8140E 00	0.4233E-03	0.8148E 00
0.1227E 01	0.2278E 00	0.9989E 00	0.5194E-03		
0.1000E-02	0.7100E 01	0.1533E 00	0.8462E 00	0.5539E-03	0.8473E 00
0.1180E 01	0.1809E 00	0.9986E 00	0.6537E-03		
0.1000E-02	0.7200E 01	0.1257E 00	0.8736E 00	0.7199E-03	0.8750E 00
0.1143E 01	0.1436E 00	0.9982E 00	0.8227E-03		
0.1000E-02	0.7300E 01	0.1025E 00	0.8966E 00	0.9302E-03	0.8985E 00
0.1113E 01	0.1140E 00	0.9978E 00	0.1035E-02		
0.1000E-02	0.7400E 01	0.8313E-01	0.9157E 00	0.1196E-02	0.9181E 00
0.1089E 01	0.9053E-01	0.9972E 00	0.1303E-02		
0.1000E-02	0.7500E 01	0.6716E-01	0.9313E 00	0.1531E-02	0.9344E 00
0.1070E 01	0.7186E-01	0.9965E 00	0.1639E-02		
0.1000E-02	0.7600E 01	0.5407E-01	0.9440E 00	0.1954E-02	0.9479E 00
0.1055E 01	0.5703E-01	0.9956E 00	0.2061E-02		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.7700E 01	0.4341E-01	0.9541E 00	0.2486E-02	0.9591E 00
0.1042E 01	0.4525E-01	0.9945E 00	0.2592E-02		
0.1000E-02	0.7800E 01	0.3477E-01	0.9621E 00	0.3156E-02	0.9684E 00
0.1032E 01	0.3589E-01	0.9931E 00	0.3258E-02		
0.1000E-02	0.7900E 01	0.2780E-01	0.9682E 00	0.3999E-02	0.9762E 00
0.1024E 01	0.2846E-01	0.9913E 00	0.4094E-02		
0.1000E-02	0.8000E 01	0.2218E-01	0.9728E 00	0.5058E-02	0.9829E 00
0.1017E 01	0.2255E-01	0.9890E 00	0.5143E-02		
0.1000E-02	0.8100E 01	0.1768E-01	0.9759E 00	0.6389E-02	0.9887E 00
0.1011E 01	0.1786E-01	0.9862E 00	0.6456E-02		
0.1000E-02	0.8200E 01	0.1407E-01	0.9779E 00	0.8059E-02	0.9940E 00
0.1005E 01	0.1414E-01	0.9827E 00	0.8099E-02		
0.1000E-02	0.8300E 01	0.1119E-01	0.9787E 00	0.1015E-01	0.9990E 00
0.9997E 00	0.1118E-01	0.9783E 00	0.1015E-01		
0.1000E-02	0.8400E 01	0.8882E-02	0.9783E 00	0.1278E-01	0.1004E 01
0.9944E 00	0.8832E-02	0.9729E 00	0.1271E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.8500E 01	0.7045E-02	0.9769E 00	0.1606E-01	0.1009E 01
0.9889E 00	0.6967E-02	0.9661E 00	0.1589E-01		
0.1000E-02	0.8600E 01	0.5581E-02	0.9743E 00	0.2017E-01	0.1015E 01
0.9830E 00	0.5486E-02	0.9576E 00	0.1982E-01		
0.1000E-02	0.8700E 01	0.4415E-02	0.9703E 00	0.2529E-01	0.1021E 01
0.9762E 00	0.4310E-02	0.9472E 00	0.2469E-01		
0.1000E-02	0.8800E 01	0.3487E-02	0.9649E 00	0.3166E-01	0.1028E 01
0.9684E 00	0.3377E-02	0.9344E 00	0.3066E-01		
0.1000E-02	0.8900E 01	0.2749E-02	0.9577E 00	0.3956E-01	0.1037E 01
0.9593E 00	0.2637E-02	0.9187E 00	0.3795E-01		
0.1000E-02	0.9000E 01	0.2163E-02	0.9485E 00	0.4932E-01	0.1047E 01
0.9485E 00	0.2052E-02	0.8996E 00	0.4678E-01		
0.1000E-02	0.9100E 01	0.1697E-02	0.9370E 00	0.6133E-01	0.1060E 01
0.9356E 00	0.1588E-02	0.8767E 00	0.5739E-01		
0.1000E-02	0.9200E 01	0.1328E-02	0.9226E 00	0.7604E-01	0.1075E 01
0.9204E 00	0.1222E-02	0.8492E 00	0.6999E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.9300E 01	0.1034E-02	0.9051E 00	0.9390E-01	0.1093E 01
0.9026E 00	0.9337E-03	0.8169E 00	0.8475E-01		
0.1000E-02	0.9400E 01	0.8023E-03	0.8838E 00	0.1154E 00	0.1115E 01
0.8818E 00	0.7075E-03	0.7793E 00	0.1018E 00		
0.1000E-02	0.9500E 01	0.6189E-03	0.8583E 00	0.1411E 00	0.1141E 01
0.8579E 00	0.5310E-03	0.7363E 00	0.1211E 00		
0.1000E-02	0.9600E 01	0.4744E-03	0.8281E 00	0.1714E 00	0.1171E 01
0.8309E 00	0.3941E-03	0.6880E 00	0.1424E 00		
0.1000E-02	0.9700E 01	0.3608E-03	0.7930E 00	0.2067E 00	0.1206E 01
0.8007E 00	0.2889E-03	0.6349E 00	0.1655E 00		
0.1000E-02	0.9800E 01	0.2721E-03	0.7528E 00	0.2470E 00	0.1247E 01
0.7677E 00	0.2089E-03	0.5779E 00	0.1896E 00		
0.1000E-02	0.9900E 01	0.2031E-03	0.7076E 00	0.2922E 00	0.1292E 01
0.7321E 00	0.1487E-03	0.5180E 00	0.2140E 00		
0.1000E-02	0.1000E 02	0.1500E-03	0.6578E 00	0.3420E 00	0.1342E 01
0.6945E 00	0.1042E-03	0.4568E 00	0.2375E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1000E 02	0.1500E-03	0.6578E 00	0.3421E 00	0.1342E 01
0.6945E 00	0.1042E-03	0.4568E 00	0.2375E 00		
0.1000E-02	0.1002E 02	0.1410E-03	0.6474E 00	0.3525E 00	0.1352E 01
0.6867E 00	0.9682E-04	0.4446E 00	0.2421E 00		
0.1000E-02	0.1004E 02	0.1324E-03	0.6368E 00	0.3631E 00	0.1363E 01
0.6789E 00	0.8992E-04	0.4323E 00	0.2465E 00		
0.1000E-02	0.1006E 02	0.1243E-03	0.6261E 00	0.3738E 00	0.1374E 01
0.6711E 00	0.8345E-04	0.4201E 00	0.2508E 00		
0.1000E-02	0.1008E 02	0.1167E-03	0.6152E 00	0.3846E 00	0.1385E 01
0.6632E 00	0.7739E-04	0.4080E 00	0.2551E 00		
0.1000E-02	0.1010E 02	0.1095E-03	0.6043E 00	0.3956E 00	0.1395E 01
0.6552E 00	0.7172E-04	0.3959E 00	0.2592E 00		
0.1000E-02	0.1012E 02	0.1026E-03	0.5932E 00	0.4067E 00	0.1407E 01
0.6472E 00	0.6641E-04	0.3839E 00	0.2632E 00		
0.1000E-02	0.1014E 02	0.9616E-04	0.5821E 00	0.4178E 00	0.1418E 01
0.6391E 00	0.6145E-04	0.3720E 00	0.2670E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1016E 02	0.9006E-04	0.5708E 00	0.4291E 00	0.1429E 01
0.6309E 00	0.5682E-04	0.3602E 00	0.2707E 00		
0.1000E-02	0.1018E 02	0.8430E-04	0.5595E 00	0.4404E 00	0.1440E 01
0.6228E 00	0.5250E-04	0.3485E 00	0.2743E 00		
0.1000E-02	0.1020E 02	0.7887E-04	0.5482E 00	0.4518E 00	0.1452E 01
0.6145E 00	0.4847E-04	0.3369E 00	0.2776E 00		
0.1000E-02	0.1022E 02	0.7375E-04	0.5367E 00	0.4632E 00	0.1463E 01
0.6063E 00	0.4471E-04	0.3254E 00	0.2808E 00		
0.1000E-02	0.1024E 02	0.6893E-04	0.5253E 00	0.4747E 00	0.1475E 01
0.5979E 00	0.4121E-04	0.3141E 00	0.2838E 00		
0.1000E-02	0.1026E 02	0.6439E-04	0.5138E 00	0.4862E 00	0.1486E 01
0.5895E 00	0.3796E-04	0.3029E 00	0.2866E 00		
0.1000E-02	0.1028E 02	0.6011E-04	0.5023E 00	0.4977E 00	0.1498E 01
0.5811E 00	0.3493E-04	0.2919E 00	0.2892E 00		
0.1000E-02	0.1030E 02	0.5609E-04	0.4908E 00	0.5092E 00	0.1509E 01
0.5726E 00	0.3212E-04	0.2810E 00	0.2916E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1032E 02	0.5231E-04	0.4793E 00	0.5207E 00	0.1521E 01
0.5641E 00	0.2951E-04	0.2703E 00	0.2937E 00		
0.1000E-02	0.1034E 02	0.4876E-04	0.4678E 00	0.5322E 00	0.1532E 01
0.5555E 00	0.2709E-04	0.2599E 00	0.2956E 00		
0.1000E-02	0.1036E 02	0.4543E-04	0.4563E 00	0.5436E 00	0.1544E 01
0.5468E 00	0.2484E-04	0.2495E 00	0.2973E 00		
0.1000E-02	0.1038E 02	0.4230E-04	0.4449E 00	0.5550E 00	0.1555E 01
0.5381E 00	0.2276E-04	0.2394E 00	0.2986E 00		
0.1000E-02	0.1040E 02	0.3937E-04	0.4336E 00	0.5664E 00	0.1566E 01
0.5293E 00	0.2083E-04	0.2295E 00	0.2998E 00		
0.1000E-02	0.1042E 02	0.3662E-04	0.4223E 00	0.5776E 00	0.1578E 01
0.5204E 00	0.1905E-04	0.2198E 00	0.3006E 00		
0.1000E-02	0.1044E 02	0.3404E-04	0.4111E 00	0.5888E 00	0.1589E 01
0.5114E 00	0.1741E-04	0.2103E 00	0.3011E 00		
0.1000E-02	0.1046E 02	0.3163E-04	0.4000E 00	0.5999E 00	0.1600E 01
0.5023E 00	0.1589E-04	0.2010E 00	0.3014E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1048E 02	0.2938E-04	0.3890E 00	0.6109E 00	0.1611E 01
0.4932E 00	0.1449E-04	0.1919E 00	0.3013E 00		
0.1000E-02	0.1050E 02	0.2727E-04	0.3782E 00	0.6218E 00	0.1622E 01
0.4839E 00	0.1320E-04	0.1830E 00	0.3009E 00		
0.1000E-02	0.1052E 02	0.2530E-04	0.3674E 00	0.6326E 00	0.1633E 01
0.4745E 00	0.1200E-04	0.1743E 00	0.3001E 00		
0.1000E-02	0.1054E 02	0.2346E-04	0.3568E 00	0.6432E 00	0.1643E 01
0.4649E 00	0.1091E-04	0.1659E 00	0.2990E 00		
0.1000E-02	0.1056E 02	0.2175E-04	0.3463E 00	0.6537E 00	0.1654E 01
0.4552E 00	0.9901E-05	0.1576E 00	0.2976E 00		
0.1000E-02	0.1058E 02	0.2015E-04	0.3359E 00	0.6641E 00	0.1664E 01
0.4454E 00	0.8975E-05	0.1496E 00	0.2958E 00		
0.1000E-02	0.1060E 02	0.1866E-04	0.3257E 00	0.6743E 00	0.1674E 01
0.4354E 00	0.8124E-05	0.1418E 00	0.2936E 00		
0.1000E-02	0.1062E 02	0.1727E-04	0.3157E 00	0.6843E 00	0.1684E 01
0.4252E 00	0.7344E-05	0.1342E 00	0.2910E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1064E 02	0.1598E-04	0.3058E 00	0.6942E 00	0.1694E 01
0.4149E 00	0.6628E-05	0.1269E 00	0.2880E 00		
0.1000E-02	0.1066E 02	0.1477E-04	0.2961E 00	0.7038E 00	0.1704E 01
0.4043E 00	0.5973E-05	0.1197E 00	0.2846E 00		
0.1000E-02	0.1068E 02	0.1366E-04	0.2866E 00	0.7134E 00	0.1713E 01
0.3935E 00	0.5374E-05	0.1128E 00	0.2807E 00		
0.1000E-02	0.1070E 02	0.1262E-04	0.2773E 00	0.7227E 00	0.1723E 01
0.3824E 00	0.4826E-05	0.1061E 00	0.2764E 00		
0.1000E-02	0.1072E 02	0.1165E-04	0.2682E 00	0.7318E 00	0.1732E 01
0.3711E 00	0.4325E-05	0.9953E-01	0.2716E 00		
0.1000E-02	0.1074E 02	0.1076E-04	0.2592E 00	0.7408E 00	0.1741E 01
0.3596E 00	0.3868E-05	0.9321E-01	0.2663E 00		
0.1000E-02	0.1076E 02	0.9927E-05	0.2505E 00	0.7495E 00	0.1749E 01
0.3477E 00	0.3451E-05	0.8709E-01	0.2606E 00		
0.1000E-02	0.1078E 02	0.9157E-05	0.2419E 00	0.7580E 00	0.1758E 01
0.3355E 00	0.3072E-05	0.8117E-01	0.2543E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1080E 02	0.8443E-05	0.2336E 00	0.7664E 00	0.1766E 01
0.3230E 00	0.2727E-05	0.7544E-01	0.2475E 00		
0.1000E-02	0.1082E 02	0.7782E-05	0.2255E 00	0.7745E 00	0.1775E 01
0.3101E 00	0.2413E-05	0.6991E-01	0.2402E 00		
0.1000E-02	0.1084E 02	0.7170E-05	0.2175E 00	0.7825E 00	0.1782E 01
0.2968E 00	0.2128E-05	0.6456E-01	0.2322E 00		
0.1000E-02	0.1086E 02	0.6604E-05	0.2098E 00	0.7902E 00	0.1790E 01
0.2831E 00	0.1870E-05	0.5939E-01	0.2237E 00		
0.1000E-02	0.1088E 02	0.6080E-05	0.2022E 00	0.7977E 00	0.1798E 01
0.2690E 00	0.1636E-05	0.5441E-01	0.2146E 00		
0.1000E-02	0.1090E 02	0.5596E-05	0.1949E 00	0.8051E 00	0.1805E 01
0.2544E 00	0.1424E-05	0.4959E-01	0.2048E 00		
0.1000E-02	0.1092E 02	0.5149E-05	0.1878E 00	0.8122E 00	0.1812E 01
0.2394E 00	0.1232E-05	0.4495E-01	0.1944E 00		
0.1000E-02	0.1094E 02	0.4736E-05	0.1809E 00	0.8191E 00	0.1819E 01
0.2238E 00	0.1060E-05	0.4048E-01	0.1833E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-02	0.1096E 02	0.4355E-05	0.1741E 00	0.8258E 00	0.1826E 01
0.2077E 00	0.9043E-06	0.3616E-01	0.1715E 00		
0.1000E-02	0.1098E 02	0.4003E-05	0.1676E 00	0.8324E 00	0.1832E 01
0.1910E 00	0.7644E-06	0.3201E-01	0.1589E 00		
0.1000E-02	0.1100E 02	0.3678E-05	0.1613E 00	0.8387E 00	0.1839E 01
0.1736E 00	0.6387E-06	0.2801E-01	0.1456E 00		
0.1000E-02	0.1102E 02	0.3379E-05	0.1552E 00	0.8448E 00	0.1845E 01
0.1557E 00	0.5261E-06	0.2415E-01	0.1315E 00		
0.1000E-02	0.1104E 02	0.3104E-05	0.1492E 00	0.8508E 00	0.1851E 01
0.1370E 00	0.4253E-06	0.2045E-01	0.1166E 00		
0.1000E-02	0.1106E 02	0.2850E-05	0.1435E 00	0.8565E 00	0.1857E 01
0.1176E 00	0.3353E-06	0.1688E-01	0.1008E 00		
0.1000E-02	0.1108E 02	0.2616E-05	0.1379E 00	0.8621E 00	0.1862E 01
0.9752E-01	0.2551E-06	0.1345E-01	0.8407E-01		
0.1000E-02	0.1110E 02	0.2401E-05	0.1325E 00	0.8675E 00	0.1867E 01
0.7658E-01	0.1838E-06	0.1015E-01	0.6643E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.6000E 01	0.6907E 00	0.3093E 00	0.1747E-04	0.3093E 00
0.6467E 01	0.4467E 01	0.2000E 01	0.1130E-03		
0.2000E-02	0.6100E 01	0.6395E 00	0.3605E 00	0.2564E-04	0.3605E 00
0.5548E 01	0.3548E 01	0.2000E 01	0.1422E-03		
0.2000E-02	0.6200E 01	0.5849E 00	0.4150E 00	0.3716E-04	0.4151E 00
0.4818E 01	0.2818E 01	0.2000E 01	0.1790E-03		
0.2000E-02	0.6300E 01	0.5281E 00	0.4718E 00	0.5318E-04	0.4719E 00
0.4238E 01	0.2238E 01	0.2000E 01	0.2254E-03		
0.2000E-02	0.6400E 01	0.4706E 00	0.5293E 00	0.7511E-04	0.5294E 00
0.3778E 01	0.1778E 01	0.1999E 01	0.2837E-03		
0.2000E-02	0.6500E 01	0.4139E 00	0.5860E 00	0.1047E-03	0.5862E 00
0.3412E 01	0.1412E 01	0.1999E 01	0.3572E-03		
0.2000E-02	0.6600E 01	0.3594E 00	0.6405E 00	0.1441E-03	0.6408E 00
0.3121E 01	0.1122E 01	0.1999E 01	0.4496E-03		
0.2000E-02	0.6700E 01	0.3082E 00	0.6916E 00	0.1958E-03	0.6920E 00
0.2890E 01	0.8908E 00	0.1999E 01	0.5660E-03		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.6800E 01	0.2614E 00	0.7384E 00	0.2632E-03	0.7389E 00
	0.2707E 01	0.7075E 00	0.1999E 01	0.7124E-03	
0.2000E-02	0.6900E 01	0.2194E 00	0.7802E 00	0.3501E-03	0.7809E 00
	0.2561E 01	0.5619E 00	0.1998E 01	0.8967E-03	
0.2000E-02	0.7000E 01	0.1825E 00	0.8170E 00	0.4616E-03	0.8180E 00
	0.2445E 01	0.4462E 00	0.1998E 01	0.1129E-02	
0.2000E-02	0.7100E 01	0.1506E 00	0.8488E 00	0.6037E-03	0.8500E 00
	0.2353E 01	0.3543E 00	0.1997E 01	0.1420E-02	
0.2000E-02	0.7200E 01	0.1234E 00	0.8758E 00	0.7841E-03	0.8774E 00
	0.2279E 01	0.2813E 00	0.1996E 01	0.1787E-02	
0.2000E-02	0.7300E 01	0.1006E 00	0.8984E 00	0.1013E-02	0.9004E 00
	0.2221E 01	0.2234E 00	0.1995E 01	0.2249E-02	
0.2000E-02	0.7400E 01	0.8155E-01	0.9171E 00	0.1301E-02	0.9197E 00
	0.2174E 01	0.1773E 00	0.1994E 01	0.2830E-02	
0.2000E-02	0.7500E 01	0.6586E-01	0.9325E 00	0.1666E-02	0.9358E 00
	0.2137E 01	0.1407E 00	0.1993E 01	0.3560E-02	

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.7600E 01	0.5301E-01	0.9449E 00	0.2125E-02	0.9491E 00
0.2107E 01	0.1117E 00	0.1991E 01	0.4477E-02		
0.2000E-02	0.7700E 01	0.4255E-01	0.9547E 00	0.2703E-02	0.9602E 00
0.2083E 01	0.8862E-01	0.1988E 01	0.5630E-02		
0.2000E-02	0.7800E 01	0.3407E-01	0.9625E 00	0.3431E-02	0.9694E 00
0.2063E 01	0.7028E-01	0.1985E 01	0.7077E-02		
0.2000E-02	0.7900E 01	0.2723E-01	0.9684E 00	0.4346E-02	0.9771E 00
0.2046E 01	0.5572E-01	0.1982E 01	0.8892E-02		
0.2000E-02	0.8000E 01	0.2173E-01	0.9728E 00	0.5495E-02	0.9838E 00
0.2032E 01	0.4416E-01	0.1977E 01	0.1117E-01		
0.2000E-02	0.8100E 01	0.1731E-01	0.9757E 00	0.6939E-02	0.9896E 00
0.2020E 01	0.3497E-01	0.1971E 01	0.1402E-01		
0.2000E-02	0.8200E 01	0.1378E-01	0.9775E 00	0.8752E-02	0.9950E 00
0.2009E 01	0.2768E-01	0.1964E 01	0.1758E-01		
0.2000E-02	0.8300E 01	0.1095E-01	0.9780E 00	0.1102E-01	0.1000E 01
0.1998E 01	0.2188E-01	0.1955E 01	0.2203E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.8400E 01	0.8692E-02	0.9774E 00	0.1387E-01	0.1005E 01
0.1988E 01	0.1728E-01	0.1943E 01	0.2757E-01		
0.2000E-02	0.8500E 01	0.6892E-02	0.9757E 00	0.1743E-01	0.1011E 01
0.1977E 01	0.1362E-01	0.1929E 01	0.3446E-01		
0.2000E-02	0.8600E 01	0.5457E-02	0.9727E 00	0.2188E-01	0.1016E 01
0.1965E 01	0.1072E-01	0.1911E 01	0.4299E-01		
0.2000E-02	0.8700E 01	0.4315E-02	0.9683E 00	0.2741E-01	0.1023E 01
0.1952E 01	0.8421E-02	0.1890E 01	0.5350E-01		
0.2000E-02	0.8800E 01	0.3407E-02	0.9623E 00	0.3430E-01	0.1031E 01
0.1936E 01	0.6595E-02	0.1863E 01	0.6640E-01		
0.2000E-02	0.8900E 01	0.2684E-02	0.9545E 00	0.4283E-01	0.1040E 01
0.1918E 01	0.5147E-02	0.1830E 01	0.8213E-01		
0.2000E-02	0.9000E 01	0.2110E-02	0.9445E 00	0.5336E-01	0.1051E 01
0.1896E 01	0.4000E-02	0.1791E 01	0.1012E 00		
0.2000E-02	0.9100E 01	0.1654E-02	0.9321E 00	0.6629E-01	0.1065E 01
0.1871E 01	0.3093E-02	0.1743E 01	0.1240E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.9200E 01	0.1292E-02	0.9166E 00	0.8207E-01	0.1081E 01
0.1841E 01	0.2378E-02	0.1687E 01	0.1511E 00		
0.2000E-02	0.9300E 01	0.1005E-02	0.8978E 00	0.1012E 00	0.1100E 01
0.1806E 01	0.1815E-02	0.1621E 01	0.1827E 00		
0.2000E-02	0.9400E 01	0.7781E-03	0.8751E 00	0.1242E 00	0.1123E 01
0.1765E 01	0.1373E-02	0.1545E 01	0.2192E 00		
0.2000E-02	0.9500E 01	0.5989E-03	0.8479E 00	0.1515E 00	0.1151E 01
0.1719E 01	0.1030E-02	0.1458E 01	0.2604E 00		
0.2000E-02	0.9600E 01	0.4579E-03	0.8160E 00	0.1835E 00	0.1183E 01
0.1668E 01	0.7635E-03	0.1361E 01	0.3060E 00		
0.2000E-02	0.9700E 01	0.3472E-03	0.7791E 00	0.2206E 00	0.1220E 01
0.1611E 01	0.5594E-03	0.1255E 01	0.3554E 00		
0.2000E-02	0.9800E 01	0.2609E-03	0.7370E 00	0.2627E 00	0.1262E 01
0.1550E 01	0.4045E-03	0.1143E 01	0.4072E 00		
0.2000E-02	0.9900E 01	0.1941E-03	0.6901E 00	0.3097E 00	0.1309E 01
0.1486E 01	0.2884E-03	0.1026E 01	0.4602E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1000E 02	0.1427E-03	0.6389E 00	0.3609E 00	0.1361E 01
0.1420E 01	0.2026E-03	0.9071E 00	0.5124E 00		
0.2000E-02	0.1002E 02	0.1340E-03	0.6282E 00	0.3716E 00	0.1372E 01
0.1406E 01	0.1884E-03	0.8835E 00	0.5226E 00		
0.2000E-02	0.1004E 02	0.1258E-03	0.6174E 00	0.3825E 00	0.1382E 01
0.1393E 01	0.1752E-03	0.8600E 00	0.5327E 00		
0.2000E-02	0.1006E 02	0.1180E-03	0.6065E 00	0.3934E 00	0.1393E 01
0.1379E 01	0.1627E-03	0.8366E 00	0.5426E 00		
0.2000E-02	0.1008E 02	0.1106E-03	0.5955E 00	0.4044E 00	0.1404E 01
0.1366E 01	0.1511E-03	0.8133E 00	0.5524E 00		
0.2000E-02	0.1010E 02	0.1037E-03	0.5843E 00	0.4156E 00	0.1415E 01
0.1352E 01	0.1402E-03	0.7902E 00	0.5620E 00		
0.2000E-02	0.1012E 02	0.9710E-04	0.5731E 00	0.4268E 00	0.1427E 01
0.1339E 01	0.1300E-03	0.7673E 00	0.5715E 00		
0.2000E-02	0.1014E 02	0.9091E-04	0.5618E 00	0.4381E 00	0.1438E 01
0.1325E 01	0.1205E-03	0.7446E 00	0.5807E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1016E 02	0.8506E-04	0.5504E 00	0.4495E 00	0.1449E 01
0.1312E 01	0.1116E-03	0.7222E 00	0.5897E 00		
0.2000E-02	0.1018E 02	0.7955E-04	0.5390E 00	0.4609E 00	0.1461E 01
0.1299E 01	0.1033E-03	0.7000E 00	0.5985E 00		
0.2000E-02	0.1020E 02	0.7435E-04	0.5276E 00	0.4724E 00	0.1472E 01
0.1285E 01	0.9555E-04	0.6780E 00	0.6071E 00		
0.2000E-02	0.1022E 02	0.6946E-04	0.5161E 00	0.4839E 00	0.1484E 01
0.1272E 01	0.8833E-04	0.6563E 00	0.6153E 00		
0.2000E-02	0.1024E 02	0.6485E-04	0.5046E 00	0.4954E 00	0.1495E 01
0.1258E 01	0.8161E-04	0.6350E 00	0.6234E 00		
0.2000E-02	0.1026E 02	0.6052E-04	0.4931E 00	0.5069E 00	0.1507E 01
0.1245E 01	0.7536E-04	0.6139E 00	0.6311E 00		
0.2000E-02	0.1028E 02	0.5645E-04	0.4816E 00	0.5184E 00	0.1518E 01
0.1232E 01	0.6954E-04	0.5932E 00	0.6385E 00		
0.2000E-02	0.1030E 02	0.5262E-04	0.4701E 00	0.5299E 00	0.1530E 01
0.1219E 01	0.6413E-04	0.5728E 00	0.6457E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1032E 02	0.4903E-04	0.4586E 00	0.5413E 00	0.1541E 01
0.1205E 01	0.5910E-04	0.5528E 00	0.6525E 00		
0.2000E-02	0.1034E 02	0.4566E-04	0.4472E 00	0.5527E 00	0.1553E 01
0.1192E 01	0.5443E-04	0.5332E 00	0.6590E 00		
0.2000E-02	0.1036E 02	0.4250E-04	0.4359E 00	0.5641E 00	0.1564E 01
0.1179E 01	0.5011E-04	0.5139E 00	0.6651E 00		
0.2000E-02	0.1038E 02	0.3953E-04	0.4246E 00	0.5754E 00	0.1575E 01
0.1166E 01	0.4609E-04	0.4950E 00	0.6708E 00		
0.2000E-02	0.1040E 02	0.3676E-04	0.4134E 00	0.5866E 00	0.1587E 01
0.1153E 01	0.4238E-04	0.4765E 00	0.6762E 00		
0.2000E-02	0.1042E 02	0.3416E-04	0.4023E 00	0.5977E 00	0.1598E 01
0.1140E 01	0.3893E-04	0.4585E 00	0.6812E 00		
0.2000E-02	0.1044E 02	0.3173E-04	0.3912E 00	0.6087E 00	0.1609E 01
0.1127E 01	0.3575E-04	0.4408E 00	0.6859E 00		
0.2000E-02	0.1046E 02	0.2946E-04	0.3803E 00	0.6196E 00	0.1620E 01
0.1114E 01	0.3280E-04	0.4235E 00	0.6901E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1048E 02	0.2733E-04	0.3695E 00	0.6304E 00	0.1630E 01
0.1101E 01	0.3008E-04	0.4067E 00	0.6939E 00		
0.2000E-02	0.1050E 02	0.2535E-04	0.3589E 00	0.6411E 00	0.1641E 01
0.1088E 01	0.2757E-04	0.3903E 00	0.6972E 00		
0.2000E-02	0.1052E 02	0.2350E-04	0.3483E 00	0.6516E 00	0.1652E 01
0.1074E 01	0.2525E-04	0.3743E 00	0.7001E 00		
0.2000E-02	0.1054E 02	0.2177E-04	0.3380E 00	0.6620E 00	0.1662E 01
0.1061E 01	0.2311E-04	0.3587E 00	0.7026E 00		
0.2000E-02	0.1056E 02	0.2016E-04	0.3277E 00	0.6722E 00	0.1672E 01
0.1048E 01	0.2114E-04	0.3435E 00	0.7046E 00		
0.2000E-02	0.1058E 02	0.1866E-04	0.3177E 00	0.6823E 00	0.1682E 01
0.1035E 01	0.1932E-04	0.3288E 00	0.7062E 00		
0.2000E-02	0.1060E 02	0.1727E-04	0.3078E 00	0.6922E 00	0.1692E 01
0.1022E 01	0.1764E-04	0.3145E 00	0.7073E 00		
0.2000E-02	0.1062E 02	0.1597E-04	0.2981E 00	0.7019E 00	0.1702E 01
0.1008E 01	0.1611E-04	0.3006E 00	0.7078E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1064E 02	0.1476E-04	0.2885E 00	0.7115E 00	0.1711E 01
	0.9950E 00	0.1469E-04	0.2871E 00	0.7079E 00	
0.2000E-02	0.1066E 02	0.1364E-04	0.2792E 00	0.7208E 00	0.1721E 01
	0.9814E 00	0.1339E-04	0.2740E 00	0.7074E 00	
0.2000E-02	0.1068E 02	0.1260E-04	0.2700E 00	0.7300E 00	0.1730E 01
	0.9677E 00	0.1219E-04	0.2613E 00	0.7065E 00	
0.2000E-02	0.1070E 02	0.1163E-04	0.2610E 00	0.7390E 00	0.1739E 01
	0.9539E 00	0.1110E-04	0.2490E 00	0.7049E 00	
0.2000E-02	0.1072E 02	0.1074E-04	0.2522E 00	0.7478E 00	0.1748E 01
	0.9399E 00	0.1009E-04	0.2371E 00	0.7028E 00	
0.2000E-02	0.1074E 02	0.9903E-05	0.2436E 00	0.7564E 00	0.1756E 01
	0.9257E 00	0.9168E-05	0.2255E 00	0.7002E 00	
0.2000E-02	0.1076E 02	0.9132E-05	0.2353E 00	0.7647E 00	0.1765E 01
	0.9113E 00	0.8322E-05	0.2144E 00	0.6969E 00	
0.2000E-02	0.1078E 02	0.8418E-05	0.2271E 00	0.7729E 00	0.1773E 01
	0.8967E 00	0.7548E-05	0.2036E 00	0.6931E 00	

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1080E 02	0.7756E-05	0.2191E 00	0.7809E 00	0.1781E 01
0.8818E 00	0.6840E-05	0.1932E 00	0.6886E 00		
0.2000E-02	0.1082E 02	0.7144E-05	0.2113E 00	0.7887E 00	0.1789E 01
0.8667E 00	0.6192E-05	0.1831E 00	0.6835E 00		
0.2000E-02	0.1084E 02	0.6578E-05	0.2037E 00	0.7963E 00	0.1796E 01
0.8512E 00	0.5600E-05	0.1734E 00	0.6778E 00		
0.2000E-02	0.1086E 02	0.6055E-05	0.1964E 00	0.8036E 00	0.1804E 01
0.8355E 00	0.5059E-05	0.1641E 00	0.6714E 00		
0.2000E-02	0.1088E 02	0.5571E-05	0.1892E 00	0.8108E 00	0.1811E 01
0.8193E 00	0.4565E-05	0.1550E 00	0.6643E 00		
0.2000E-02	0.1090E 02	0.5125E-05	0.1822E 00	0.8178E 00	0.1818E 01
0.8028E 00	0.4114E-05	0.1463E 00	0.6565E 00		
0.2000E-02	0.1092E 02	0.4712E-05	0.1755E 00	0.8245E 00	0.1825E 01
0.7858E 00	0.3703E-05	0.1379E 00	0.6479E 00		
0.2000E-02	0.1094E 02	0.4332E-05	0.1689E 00	0.8311E 00	0.1831E 01
0.7685E 00	0.3329E-05	0.1298E 00	0.6387E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1096E 02	0.3981E-05	0.1625E 00	0.8374E 00	0.1837E 01
0.7506E 00	0.2988E-05	0.1220E 00	0.6286E 00		
0.2000E-02	0.1098E 02	0.3658E-05	0.1564E 00	0.8436E 00	0.1844E 01
0.7322E 00	0.2678E-05	0.1145E 00	0.6177E 00		
0.2000E-02	0.1100E 02	0.3359E-05	0.1504E 00	0.8496E 00	0.1850E 01
0.7133E 00	0.2396E-05	0.1073E 00	0.6060E 00		
0.2000E-02	0.1102E 02	0.3085E-05	0.1446E 00	0.8554E 00	0.1855E 01
0.6938E 00	0.2140E-05	0.1003E 00	0.5934E 00		
0.2000E-02	0.1104E 02	0.2832E-05	0.1390E 00	0.8610E 00	0.1861E 01
0.6736E 00	0.1908E-05	0.9363E-01	0.5800E 00		
0.2000E-02	0.1106E 02	0.2599E-05	0.1336E 00	0.8664E 00	0.1866E 01
0.6528E 00	0.1697E-05	0.8720E-01	0.5656E 00		
0.2000E-02	0.1108E 02	0.2385E-05	0.1283E 00	0.8717E 00	0.1872E 01
0.6313E 00	0.1505E-05	0.8102E-01	0.5503E 00		
0.2000E-02	0.1110E 02	0.2187E-05	0.1233E 00	0.8767E 00	0.1877E 01
0.6090E 00	0.1332E-05	0.7508E-01	0.5340E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1112E 02	0.2006E-05	0.1184E 00	0.8816E 00	0.1882E 01
0.5860E 00	0.1176E-05	0.6937E-01	0.5166E 00		
0.2000E-02	0.1114E 02	0.1839E-05	0.1137E 00	0.8863E 00	0.1886E 01
0.5621E 00	0.1034E-05	0.6389E-01	0.4982E 00		
0.2000E-02	0.1116E 02	0.1686E-05	0.1091E 00	0.8909E 00	0.1891E 01
0.5373E 00	0.9060E-06	0.5863E-01	0.4787E 00		
0.2000E-02	0.1118E 02	0.1545E-05	0.1047E 00	0.8953E 00	0.1895E 01
0.5116E 00	0.7907E-06	0.5357E-01	0.4581E 00		
0.2000E-02	0.1120E 02	0.1416E-05	0.1005E 00	0.8995E 00	0.1900E 01
0.4849E 00	0.6867E-06	0.4872E-01	0.4362E 00		
0.2000E-02	0.1122E 02	0.1297E-05	0.9639E-01	0.9036E 00	0.1904E 01
0.4572E 00	0.5931E-06	0.4406E-01	0.4131E 00		
0.2000E-02	0.1124E 02	0.1188E-05	0.9245E-01	0.9076E 00	0.1908E 01
0.4283E 00	0.5090E-06	0.3960E-01	0.3887E 00		
0.2000E-02	0.1126E 02	0.1088E-05	0.8866E-01	0.9113E 00	0.1911E 01
0.3983E 00	0.4335E-06	0.3531E-01	0.3630E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.2000E-02	0.1128E 02	0.9965E-06	0.8501E-01	0.9150E 00	0.1915E 01
0.3671E 00	0.3658E-06	0.3120E-01	0.3359E 00		
0.2000E-02	0.1130E 02	0.9124E-06	0.8149E-01	0.9185E 00	0.1919E 01
0.3345E 00	0.3052E-06	0.2726E-01	0.3073E 00		
0.4000E-02	0.6000E 01	0.6848E 00	0.3152E 00	0.1781E-04	0.3152E 00
0.1269E 02	0.8690E 01	0.4000E 01	0.2260E-03		
0.4000E-02	0.6100E 01	0.6331E 00	0.3668E 00	0.2609E-04	0.3669E 00
0.1090E 02	0.6902E 01	0.3999E 01	0.2844E-03		
0.4000E-02	0.6200E 01	0.5782E 00	0.4218E 00	0.3776E-04	0.4218E 00
0.9482E 01	0.5483E 01	0.3999E 01	0.3581E-03		
0.4000E-02	0.6300E 01	0.5213E 00	0.4787E 00	0.5396E-04	0.4788E 00
0.8354E 01	0.4355E 01	0.3999E 01	0.4508E-03		
0.4000E-02	0.6400E 01	0.4638E 00	0.5362E 00	0.7608E-04	0.5363E 00
0.7458E 01	0.3459E 01	0.3999E 01	0.5675E-03		
0.4000E-02	0.6500E 01	0.4072E 00	0.5927E 00	0.1059E-03	0.5929E 00
0.6747E 01	0.2747E 01	0.3999E 01	0.7143E-03		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.6600E 01	0.3530E 00	0.6468E 00	0.1455E-03	0.6471E 00
0.6181E 01	0.2182E 01	0.3998E 01	0.8992E-03		
0.4000E-02	0.6700E 01	0.3024E 00	0.6974E 00	0.1975E-03	0.6978E 00
0.5732E 01	0.1733E 01	0.3998E 01	0.1132E-02		
0.4000E-02	0.6800E 01	0.2561E 00	0.7437E 00	0.2651E-03	0.7442E 00
0.5375E 01	0.1376E 01	0.3997E 01	0.1425E-02		
0.4000E-02	0.6900E 01	0.2147E 00	0.7849E 00	0.3522E-03	0.7856E 00
0.5091E 01	0.1093E 01	0.3996E 01	0.1793E-02		
0.4000E-02	0.7000E 01	0.1784E 00	0.8211E 00	0.4639E-03	0.8221E 00
0.4866E 01	0.8681E 00	0.3995E 01	0.2257E-02		
0.4000E-02	0.7100E 01	0.1471E 00	0.8523E 00	0.6062E-03	0.8535E 00
0.4686E 01	0.6893E 00	0.3994E 01	0.2841E-02		
0.4000E-02	0.7200E 01	0.1205E 00	0.8787E 00	0.7868E-03	0.8803E 00
0.4544E 01	0.5474E 00	0.3993E 01	0.3575E-02		
0.4000E-02	0.7300E 01	0.9810E-01	0.9009E 00	0.1015E-02	0.9029E 00
0.4430E 01	0.4346E 00	0.3991E 01	0.4498E-02		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.7400E 01	0.7951E-01	0.9192E 00	0.1304E-02	0.9218E 00
0.4339E 01	0.3450E 00	0.3989E 01	0.5660E-02		
0.4000E-02	0.7500E 01	0.6418E-01	0.9341E 00	0.1669E-02	0.9375E 00
0.4266E 01	0.2738E 00	0.3986E 01	0.7120E-02		
0.4000E-02	0.7600E 01	0.5164E-01	0.9462E 00	0.2128E-02	0.9505E 00
0.4208E 01	0.2173E 00	0.3982E 01	0.8955E-02		
0.4000E-02	0.7700E 01	0.4144E-01	0.9559E 00	0.2706E-02	0.9613E 00
0.4161E 01	0.1724E 00	0.3977E 01	0.1126E-01		
0.4000E-02	0.7800E 01	0.3318E-01	0.9634E 00	0.3434E-02	0.9703E 00
0.4122E 01	0.1368E 00	0.3971E 01	0.1416E-01		
0.4000E-02	0.7900E 01	0.2651E-01	0.9691E 00	0.4349E-02	0.9778E 00
0.4090E 01	0.1084E 00	0.3964E 01	0.1779E-01		
0.4000E-02	0.8000E 01	0.2115E-01	0.9734E 00	0.5499E-02	0.9844E 00
0.4063E 01	0.8592E-01	0.3955E 01	0.2234E-01		
0.4000E-02	0.8100E 01	0.1685E-01	0.9762E 00	0.6943E-02	0.9901E 00
0.4039E 01	0.6805E-01	0.3943E 01	0.2804E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.8200E 01	0.1341E-01	0.9778E 00	0.8755E-02	0.9954E 00
0.4018E 01	0.5386E-01	0.3929E 01	0.3517E-01		
0.4000E-02	0.8300E 01	0.1065E-01	0.9783E 00	0.1103E-01	0.1000E 01
0.3997E 01	0.4258E-01	0.3910E 01	0.4408E-01		
0.4000E-02	0.8400E 01	0.8457E-02	0.9777E 00	0.1387E-01	0.1005E 01
0.3977E 01	0.3363E-01	0.3888E 01	0.5517E-01		
0.4000E-02	0.8500E 01	0.6705E-02	0.9759E 00	0.1743E-01	0.1011E 01
0.3955E 01	0.2652E-01	0.3860E 01	0.6896E-01		
0.4000E-02	0.8600E 01	0.5309E-02	0.9728E 00	0.2188E-01	0.1017E 01
0.3932E 01	0.2088E-01	0.3825E 01	0.8603E-01		
0.4000E-02	0.8700E 01	0.4198E-02	0.9684E 00	0.2742E-01	0.1023E 01
0.3906E 01	0.1640E-01	0.3782E 01	0.1071E 00		
0.4000E-02	0.8800E 01	0.3314E-02	0.9624E 00	0.3430E-01	0.1031E 01
0.3876E 01	0.1284E-01	0.3730E 01	0.1329E 00		
0.4000E-02	0.8900E 01	0.2611E-02	0.9546E 00	0.4283E-01	0.1040E 01
0.3840E 01	0.1003E-01	0.3666E 01	0.1645E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.9000E 01	0.2052E-02	0.9446E 00	0.5336E-01	0.1051E 01
0.3798E 01	0.7796E-02	0.3588E 01	0.2027E 00		
0.4000E-02	0.9100E 01	0.1609E-02	0.9321E 00	0.6629E-01	0.1065E 01
0.3749E 01	0.6031E-02	0.3494E 01	0.2485E 00		
0.4000E-02	0.9200E 01	0.1257E-02	0.9167E 00	0.8207E-01	0.1081E 01
0.3691E 01	0.4638E-02	0.3383E 01	0.3029E 00		
0.4000E-02	0.9300E 01	0.9777E-03	0.8978E 00	0.1012E 00	0.1100E 01
0.3623E 01	0.3543E-02	0.3253E 01	0.3667E 00		
0.4000E-02	0.9400E 01	0.7569E-03	0.8751E 00	0.1242E 00	0.1123E 01
0.3545E 01	0.2684E-02	0.3102E 01	0.4402E 00		
0.4000E-02	0.9500E 01	0.5826E-03	0.8479E 00	0.1515E 00	0.1151E 01
0.3457E 01	0.2014E-02	0.2931E 01	0.5236E 00		
0.4000E-02	0.9600E 01	0.4454E-03	0.8160E 00	0.1835E 00	0.1183E 01
0.3358E 01	0.1496E-02	0.2740E 01	0.6163E 00		
0.4000E-02	0.9700E 01	0.3378E-03	0.7791E 00	0.2206E 00	0.1220E 01
0.3250E 01	0.1098E-02	0.2532E 01	0.7169E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.9800E 01	0.2538E-03	0.7370E 00	0.2627E 00	0.1262E 01
0.3134E 01	0.7956E-03	0.2310E 01	0.8234E 00		
0.4000E-02	0.9900E 01	0.1888E-03	0.6901E 00	0.3097E 00	0.1309E 01
0.3013E 01	0.5689E-03	0.2080E 01	0.9332E 00		
0.4000E-02	0.1000E 02	0.1388E-03	0.6389E 00	0.3609E 00	0.1361E 01
0.2889E 01	0.4011E-03	0.1846E 01	0.1043E 01		
0.4000E-02	0.1002E 02	0.1304E-03	0.6282E 00	0.3716E 00	0.1372E 01
0.2865E 01	0.3734E-03	0.1800E 01	0.1065E 01		
0.4000E-02	0.1004E 02	0.1223E-03	0.6174E 00	0.3825E 00	0.1382E 01
0.2840E 01	0.3474E-03	0.1753E 01	0.1086E 01		
0.4000E-02	0.1006E 02	0.1148E-03	0.6065E 00	0.3934E 00	0.1393E 01
0.2815E 01	0.3231E-03	0.1707E 01	0.1107E 01		
0.4000E-02	0.1008E 02	0.1076E-03	0.5955E 00	0.4044E 00	0.1404E 01
0.2790E 01	0.3002E-03	0.1661E 01	0.1128E 01		
0.4000E-02	0.1010E 02	0.1008E-03	0.5843E 00	0.4156E 00	0.1415E 01
0.2765E 01	0.2789E-03	0.1616E 01	0.1149E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1012E 02	0.9446E-04	0.5731E 00	0.4268E 00	0.1427E 01
0.2741E 01	0.2589E-03	0.1571E 01	0.1170E 01		
0.4000E-02	0.1014E 02	0.8843E-04	0.5618E 00	0.4381E 00	0.1438E 01
0.2716E 01	0.2402E-03	0.1526E 01	0.1190E 01		
0.4000E-02	0.1016E 02	0.8274E-04	0.5504E 00	0.4495E 00	0.1449E 01
0.2692E 01	0.2227E-03	0.1482E 01	0.1210E 01		
0.4000E-02	0.1018E 02	0.7738E-04	0.5390E 00	0.4609E 00	0.1461E 01
0.2668E 01	0.2064E-03	0.1438E 01	0.1230E 01		
0.4000E-02	0.1020E 02	0.7233E-04	0.5276E 00	0.4724E 00	0.1472E 01
0.2644E 01	0.1912E-03	0.1395E 01	0.1249E 01		
0.4000E-02	0.1022E 02	0.6757E-04	0.5161E 00	0.4839E 00	0.1484E 01
0.2620E 01	0.1770E-03	0.1352E 01	0.1268E 01		
0.4000E-02	0.1024E 02	0.6309E-04	0.5046E 00	0.4954E 00	0.1495E 01
0.2596E 01	0.1638E-03	0.1310E 01	0.1286E 01		
0.4000E-02	0.1026E 02	0.5887E-04	0.4931E 00	0.5069E 00	0.1507E 01
0.2572E 01	0.1514E-03	0.1268E 01	0.1304E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1028E 02	0.5491E-04	0.4816E 00	0.5184E 00	0.1518E 01
0.2549E 01	0.1400E-03	0.1228E 01	0.1321E 01		
0.4000E-02	0.1030E 02	0.5119E-04	0.4701E 00	0.5299E 00	0.1530E 01
0.2526E 01	0.1293E-03	0.1187E 01	0.1338E 01		
0.4000E-02	0.1032E 02	0.4769E-04	0.4586E 00	0.5413E 00	0.1541E 01
0.2503E 01	0.1194E-03	0.1148E 01	0.1355E 01		
0.4000E-02	0.1034E 02	0.4442E-04	0.4472E 00	0.5527E 00	0.1553E 01
0.2480E 01	0.1102E-03	0.1109E 01	0.1371E 01		
0.4000E-02	0.1036E 02	0.4134E-04	0.4359E 00	0.5641E 00	0.1564E 01
0.2458E 01	0.1016E-03	0.1071E 01	0.1386E 01		
0.4000E-02	0.1038E 02	0.3846E-04	0.4246E 00	0.5754E 00	0.1575E 01
0.2435E 01	0.9366E-04	0.1034E 01	0.1401E 01		
0.4000E-02	0.1040E 02	0.3576E-04	0.4134E 00	0.5866E 00	0.1587E 01
0.2413E 01	0.8630E-04	0.9976E 00	0.1416E 01		
0.4000E-02	0.1042E 02	0.3323E-04	0.4023E 00	0.5977E 00	0.1598E 01
0.2392E 01	0.7947E-04	0.9620E 00	0.1429E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1044E 02	0.3086E-04	0.3912E 00	0.6087E 00	0.1609E 01
0.2370E 01	0.7315E-04	0.9272E 00	0.1443E 01		
0.4000E-02	0.1046E 02	0.2865E-04	0.3803E 00	0.6196E 00	0.1620E 01
0.2348E 01	0.6729E-04	0.8932E 00	0.1455E 01		
0.4000E-02	0.1048E 02	0.2659E-04	0.3695E 00	0.6304E 00	0.1630E 01
0.2327E 01	0.6187E-04	0.8600E 00	0.1467E 01		
0.4000E-02	0.1050E 02	0.2466E-04	0.3589E 00	0.6411E 00	0.1641E 01
0.2306E 01	0.5687E-04	0.8276E 00	0.1479E 01		
0.4000E-02	0.1052E 02	0.2286E-04	0.3483E 00	0.6516E 00	0.1652E 01
0.2285E 01	0.5224E-04	0.7961E 00	0.1489E 01		
0.4000E-02	0.1054E 02	0.2118E-04	0.3380E 00	0.6620E 00	0.1662E 01
0.2265E 01	0.4796E-04	0.7654E 00	0.1499E 01		
0.4000E-02	0.1056E 02	0.1961E-04	0.3277E 00	0.6722E 00	0.1672E 01
0.2244E 01	0.4402E-04	0.7355E 00	0.1509E 01		
0.4000E-02	0.1058E 02	0.1816E-04	0.3177E 00	0.6823E 00	0.1682E 01
0.2224E 01	0.4038E-04	0.7065E 00	0.1517E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1060E 02	0.1680E-04	0.3078E 00	0.6922E 00	0.1692E 01
0.2204E 01	0.3702E-04	0.6782E 00	0.1525E 01		
0.4000E-02	0.1062E 02	0.1554E-04	0.2981E 00	0.7019E 00	0.1702E 01
0.2184E 01	0.3392E-04	0.6508E 00	0.1533E 01		
0.4000E-02	0.1064E 02	0.1436E-04	0.2885E 00	0.7115E 00	0.1711E 01
0.2164E 01	0.3107E-04	0.6242E 00	0.1539E 01		
0.4000E-02	0.1066E 02	0.1327E-04	0.2792E 00	0.7208E 00	0.1721E 01
0.2144E 01	0.2845E-04	0.5984E 00	0.1545E 01		
0.4000E-02	0.1068E 02	0.1226E-04	0.2700E 00	0.7300E 00	0.1730E 01
0.2124E 01	0.2603E-04	0.5734E 00	0.1550E 01		
0.4000E-02	0.1070E 02	0.1132E-04	0.2610E 00	0.7390E 00	0.1739E 01
0.2104E 01	0.2381E-04	0.5492E 00	0.1555E 01		
0.4000E-02	0.1072E 02	0.1044E-04	0.2522E 00	0.7478E 00	0.1748E 01
0.2084E 01	0.2176E-04	0.5257E 00	0.1559E 01		
0.4000E-02	0.1074E 02	0.9633E-05	0.2436E 00	0.7564E 00	0.1756E 01
0.2064E 01	0.1989E-04	0.5030E 00	0.1561E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1076E 02	0.8883E-05	0.2353E 00	0.7647E 00	0.1765E 01
0.2045E 01	0.1816E-04	0.4810E 00	0.1564E 01		
0.4000E-02	0.1078E 02	0.8188E-05	0.2271E 00	0.7729E 00	0.1773E 01
0.2025E 01	0.1658E-04	0.4598E 00	0.1565E 01		
0.4000E-02	0.1080E 02	0.7545E-05	0.2191E 00	0.7809E 00	0.1781E 01
0.2005E 01	0.1513E-04	0.4392E 00	0.1566E 01		
0.4000E-02	0.1082E 02	0.6949E-05	0.2113E 00	0.7887E 00	0.1789E 01
0.1985E 01	0.1379E-04	0.4194E 00	0.1565E 01		
0.4000E-02	0.1084E 02	0.6399E-05	0.2037E 00	0.7963E 00	0.1796E 01
0.1965E 01	0.1257E-04	0.4003E 00	0.1564E 01		
0.4000E-02	0.1086E 02	0.5890E-05	0.1964E 00	0.8036E 00	0.1804E 01
0.1944E 01	0.1145E-04	0.3818E 00	0.1563E 01		
0.4000E-02	0.1088E 02	0.5419E-05	0.1892E 00	0.8108E 00	0.1811E 01
0.1924E 01	0.1043E-04	0.3640E 00	0.1560E 01		
0.4000E-02	0.1090E 02	0.4985E-05	0.1822E 00	0.8178E 00	0.1818E 01
0.1903E 01	0.9487E-05	0.3468E 00	0.1556E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1092E 02	0.4584E-05	0.1755E 00	0.8245E 00	0.1825E 01
0.1882E 01	0.8627E-05	0.3303E 00	0.1552E 01		
0.4000E-02	0.1094E 02	0.4214E-05	0.1689E 00	0.8311E 00	0.1831E 01
0.1861E 01	0.7841E-05	0.3143E 00	0.1546E 01		
0.4000E-02	0.1096E 02	0.3873E-05	0.1625E 00	0.8374E 00	0.1837E 01
0.1839E 01	0.7122E-05	0.2989E 00	0.1540E 01		
0.4000E-02	0.1098E 02	0.3558E-05	0.1564E 00	0.8436E 00	0.1844E 01
0.1817E 01	0.6465E-05	0.2841E 00	0.1533E 01		
0.4000E-02	0.1100E 02	0.3268E-05	0.1504E 00	0.8496E 00	0.1850E 01
0.1795E 01	0.5865E-05	0.2699E 00	0.1525E 01		
0.4000E-02	0.1102E 02	0.3001E-05	0.1446E 00	0.8554E 00	0.1855E 01
0.1772E 01	0.5316E-05	0.2562E 00	0.1515E 01		
0.4000E-02	0.1104E 02	0.2755E-05	0.1390E 00	0.8610E 00	0.1861E 01
0.1748E 01	0.4816E-05	0.2430E 00	0.1505E 01		
0.4000E-02	0.1106E 02	0.2528E-05	0.1336E 00	0.8664E 00	0.1866E 01
0.1724E 01	0.4359E-05	0.2303E 00	0.1494E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.4000E-02	0.1108E 02	0.2320E-05	0.1283E 00	0.8717E 00	0.1872E 01
0.1700E 01	0.3943E-05	0.2182E 00	0.1482E 01		
0.4000E-02	0.1110E 02	0.2128E-05	0.1233E 00	0.8767E 00	0.1877E 01
0.1675E 01	0.3563E-05	0.2065E 00	0.1468E 01		
0.4000E-02	0.1112E 02	0.1951E-05	0.1184E 00	0.8816E 00	0.1882E 01
0.1649E 01	0.3218E-05	0.1952E 00	0.1454E 01		
0.4000E-02	0.1114E 02	0.1789E-05	0.1137E 00	0.8863E 00	0.1886E 01
0.1622E 01	0.2903E-05	0.1844E 00	0.1438E 01		
0.4000E-02	0.1116E 02	0.1640E-05	0.1091E 00	0.8909E 00	0.1891E 01
0.1595E 01	0.2616E-05	0.1740E 00	0.1421E 01		
0.4000E-02	0.1118E 02	0.1503E-05	0.1047E 00	0.8953E 00	0.1895E 01
0.1567E 01	0.2355E-05	0.1641E 00	0.1403E 01		
0.4000E-02	0.1120E 02	0.1377E-05	0.1005E 00	0.8995E 00	0.1900E 01
0.1538E 01	0.2118E-05	0.1545E 00	0.1383E 01		
0.1000E-01	0.6000E 01	0.6744E 00	0.3256E 00	0.1839E-04	0.3256E 00
0.3071E 02	0.2071E 02	0.9999E 01	0.5649E-03		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.6100E 01	0.6220E 00	0.3780E 00	0.2688E-04	0.3780E 00
0.2645E 02	0.1645E 02	0.9999E 01	0.7111E-03		
0.1000E-01	0.6200E 01	0.5665E 00	0.4334E 00	0.3881E-04	0.4335E 00
0.2307E 02	0.1307E 02	0.9998E 01	0.8952E-03		
0.1000E-01	0.6300E 01	0.5094E 00	0.4906E 00	0.5530E-04	0.4907E 00
0.2038E 02	0.1038E 02	0.9998E 01	0.1127E-02		
0.1000E-01	0.6400E 01	0.4519E 00	0.5480E 00	0.7776E-04	0.5481E 00
0.1824E 02	0.8245E 01	0.9997E 01	0.1419E-02		
0.1000E-01	0.6500E 01	0.3958E 00	0.6041E 00	0.1079E-03	0.6043E 00
0.1655E 02	0.6549E 01	0.9996E 01	0.1786E-02		
0.1000E-01	0.6600E 01	0.3422E 00	0.6576E 00	0.1479E-03	0.6579E 00
0.1520E 02	0.5201E 01	0.9995E 01	0.2248E-02		
0.1000E-01	0.6700E 01	0.2924E 00	0.7074E 00	0.2003E-03	0.7078E 00
0.1413E 02	0.4131E 01	0.9994E 01	0.2830E-02		
0.1000E-01	0.6800E 01	0.2471E 00	0.7526E 00	0.2683E-03	0.7532E 00
0.1328E 02	0.3281E 01	0.9993E 01	0.3562E-02		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.6900E 01	0.2068E 00	0.7929E 00	0.3558E-03	0.7936E 00
0.1260E 02	0.2606E 01	0.9991E 01	0.4483E-02		
0.1000E-01	0.7000E 01	0.1715E 00	0.8280E 00	0.4678E-03	0.8289E 00
0.1206E 02	0.2069E 01	0.9989E 01	0.5643E-02		
0.1000E-01	0.7100E 01	0.1412E 00	0.8582E 00	0.6103E-03	0.8594E 00
0.1164E 02	0.1643E 01	0.9986E 01	0.7102E-02		
0.1000E-01	0.7200E 01	0.1155E 00	0.8837E 00	0.7912E-03	0.8853E 00
0.1130E 02	0.1305E 01	0.9982E 01	0.8937E-02		
0.1000E-01	0.7300E 01	0.9396E-01	0.9050E 00	0.1020E-02	0.9071E 00
0.1102E 02	0.1036E 01	0.9977E 01	0.1125E-01		
0.1000E-01	0.7400E 01	0.7609E-01	0.9226E 00	0.1309E-02	0.9252E 00
0.1081E 02	0.8224E 00	0.9972E 01	0.1415E-01		
0.1000E-01	0.7500E 01	0.6138E-01	0.9369E 00	0.1674E-02	0.9403E 00
0.1063E 02	0.6528E 00	0.9964E 01	0.1780E-01		
0.1000E-01	0.7600E 01	0.4936E-01	0.9485E 00	0.2133E-02	0.9528E 00
0.1050E 02	0.5180E 00	0.9955E 01	0.2239E-01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.7700E 01	0.3959E-01	0.9577E 00	0.2712E-02	0.9631E 00
0.1038E 02	0.4110E 00	0.9943E 01	0.2815E-01		
0.1000E-01	0.7800E 01	0.3168E-01	0.9649E 00	0.3439E-02	0.9718E 00
0.1029E 02	0.3260E 00	0.9929E 01	0.3539E-01		
0.1000E-01	0.7900E 01	0.2531E-01	0.9703E 00	0.4354E-02	0.9790E 00
0.1021E 02	0.2585E 00	0.9911E 01	0.4447E-01		
0.1000E-01	0.8000E 01	0.2018E-01	0.9743E 00	0.5504E-02	0.9853E 00
0.1015E 02	0.2048E 00	0.9888E 01	0.5586E-01		
0.1000E-01	0.8100E 01	0.1608E-01	0.9770E 00	0.6948E-02	0.9909E 00
0.1009E 02	0.1622E 00	0.9859E 01	0.7012E-01		
0.1000E-01	0.8200E 01	0.1279E-01	0.9785E 00	0.8760E-02	0.9960E 00
0.1004E 02	0.1284E 00	0.9823E 01	0.8795E-01		
0.1000E-01	0.8300E 01	0.1016E-01	0.9788E 00	0.1103E-01	0.1001E 01
0.9990E 01	0.1015E 00	0.9778E 01	0.1102E 00		
0.1000E-01	0.8400E 01	0.8066E-02	0.9781E 00	0.1388E-01	0.1006E 01
0.9941E 01	0.8018E-01	0.9722E 01	0.1380E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.8500E 01	0.6395E-02	0.9762E 00	0.1744E-01	0.1011E 01
0.9889E 01	0.6324E-01	0.9653E 01	0.1724E 00		
0.1000E-01	0.8600E 01	0.5064E-02	0.9731E 00	0.2188E-01	0.1017E 01
0.9832E 01	0.4978E-01	0.9567E 01	0.2152E 00		
0.1000E-01	0.8700E 01	0.4004E-02	0.9686E 00	0.2742E-01	0.1023E 01
0.9768E 01	0.3911E-01	0.9461E 01	0.2679E 00		
0.1000E-01	0.8800E 01	0.3160E-02	0.9625E 00	0.3431E-01	0.1031E 01
0.9694E 01	0.3064E-01	0.9331E 01	0.3326E 00		
0.1000E-01	0.8900E 01	0.2490E-02	0.9547E 00	0.4284E-01	0.1040E 01
0.9607E 01	0.2392E-01	0.9171E 01	0.4116E 00		
0.1000E-01	0.9000E 01	0.1957E-02	0.9447E 00	0.5337E-01	0.1051E 01
0.9505E 01	0.1860E-01	0.8979E 01	0.5072E 00		
0.1000E-01	0.9100E 01	0.1534E-02	0.9322E 00	0.6629E-01	0.1065E 01
0.9384E 01	0.1439E-01	0.8747E 01	0.6221E 00		
0.1000E-01	0.9200E 01	0.1198E-02	0.9167E 00	0.8208E-01	0.1081E 01
0.9242E 01	0.1107E-01	0.8472E 01	0.7585E 00		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.9300E 01	0.9322E-03	0.8979E 00	0.1012E 00	0.1100E 01
	0.9076E 01	0.8461E-02	0.8149E 01	0.9186E 00	
0.1000E-01	0.9400E 01	0.7217E-03	0.8751E 00	0.1242E 00	0.1123E 01
	0.8886E 01	0.6413E-02	0.7776E 01	0.1103E 01	
0.1000E-01	0.9500E 01	0.5555E-03	0.8480E 00	0.1515E 00	0.1151E 01
	0.8670E 01	0.4816E-02	0.7352E 01	0.1313E 01	
0.1000E-01	0.9600E 01	0.4247E-03	0.8160E 00	0.1835E 00	0.1183E 01
	0.8429E 01	0.3580E-02	0.6879E 01	0.1547E 01	
0.1000E-01	0.9700E 01	0.3220E-03	0.7791E 00	0.2206E 00	0.1220E 01
	0.8167E 01	0.2630E-02	0.6363E 01	0.1801E 01	
0.1000E-01	0.9800E 01	0.2420E-03	0.7370E 00	0.2627E 00	0.1262E 01
	0.7887E 01	0.1909E-02	0.5813E 01	0.2072E 01	
0.1000E-01	0.9900E 01	0.1800E-03	0.6901E 00	0.3097E 00	0.1310E 01
	0.7595E 01	0.1367E-02	0.5242E 01	0.2352E 01	
0.1000E-01	0.1000E 02	0.1324E-03	0.6389E 00	0.3609E 00	0.1361E 01
	0.7299E 01	0.9661E-03	0.4663E 01	0.2634E 01	

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1002E 02	0.1243E-03	0.6282E 00	0.3716E 00	0.1372E 01
0.7239E 01	0.8997E-03	0.4548E 01	0.2690E 01		
0.1000E-01	0.1004E 02	0.1167E-03	0.6174E 00	0.3825E 00	0.1382E 01
0.7180E 01	0.8376E-03	0.4433E 01	0.2746E 01		
0.1000E-01	0.1006E 02	0.1094E-03	0.6065E 00	0.3934E 00	0.1393E 01
0.7121E 01	0.7793E-03	0.4319E 01	0.2801E 01		
0.1000E-01	0.1008E 02	0.1026E-03	0.5955E 00	0.4044E 00	0.1404E 01
0.7063E 01	0.7246E-03	0.4205E 01	0.2856E 01		
0.1000E-01	0.1010E 02	0.9615E-04	0.5843E 00	0.4156E 00	0.1415E 01
0.7004E 01	0.6735E-03	0.4093E 01	0.2911E 01		
0.1000E-01	0.1012E 02	0.9006E-04	0.5731E 00	0.4268E 00	0.1427E 01
0.6946E 01	0.6256E-03	0.3981E 01	0.2965E 01		
0.1000E-01	0.1014E 02	0.8431E-04	0.5618E 00	0.4381E 00	0.1438E 01
0.6889E 01	0.5808E-03	0.3870E 01	0.3018E 01		
0.1000E-01	0.1016E 02	0.7889E-04	0.5504E 00	0.4495E 00	0.1449E 01
0.6832E 01	0.5389E-03	0.3760E 01	0.3071E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1018E 02	0.7378E-04	0.5390E 00	0.4609E 00	0.1461E 01
	0.6775E 01	0.4998E-03	0.3652E 01	0.3123E 01	
0.1000E-01	0.1020E 02	0.6896E-04	0.5276E 00	0.4724E 00	0.1472E 01
	0.6719E 01	0.4633E-03	0.3545E 01	0.3174E 01	
0.1000E-01	0.1022E 02	0.6442E-04	0.5161E 00	0.4839E 00	0.1484E 01
	0.6663E 01	0.4293E-03	0.3439E 01	0.3224E 01	
0.1000E-01	0.1024E 02	0.6015E-04	0.5046E 00	0.4954E 00	0.1495E 01
	0.6608E 01	0.3975E-03	0.3334E 01	0.3274E 01	
0.1000E-01	0.1026E 02	0.5613E-04	0.4931E 00	0.5069E 00	0.1507E 01
	0.6554E 01	0.3679E-03	0.3232E 01	0.3322E 01	
0.1000E-01	0.1028E 02	0.5236E-04	0.4816E 00	0.5184E 00	0.1518E 01
	0.6501E 01	0.3404E-03	0.3131E 01	0.3370E 01	
0.1000E-01	0.1030E 02	0.4881E-04	0.4701E 00	0.5299E 00	0.1530E 01
	0.6448E 01	0.3147E-03	0.3031E 01	0.3417E 01	
0.1000E-01	0.1032E 02	0.4547E-04	0.4586E 00	0.5413E 00	0.1541E 01
	0.6396E 01	0.2909E-03	0.2933E 01	0.3462E 01	

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1034E 02	0.4235E-04	0.4472E 00	0.5527E 00	0.1553E 01
0.6345E 01	0.2687E-03	0.2837E 01	0.3507E 01		
0.1000E-01	0.1036E 02	0.3942E-04	0.4359E 00	0.5641E 00	0.1564E 01
0.6294E 01	0.2481E-03	0.2743E 01	0.3550E 01		
0.1000E-01	0.1038E 02	0.3667E-04	0.4246E 00	0.5754E 00	0.1575E 01
0.6244E 01	0.2290E-03	0.2651E 01	0.3593E 01		
0.1000E-01	0.1040E 02	0.3409E-04	0.4134E 00	0.5866E 00	0.1587E 01
0.6195E 01	0.2112E-03	0.2561E 01	0.3634E 01		
0.1000E-01	0.1042E 02	0.3168E-04	0.4023E 00	0.5977E 00	0.1598E 01
0.6147E 01	0.1948E-03	0.2473E 01	0.3674E 01		
0.1000E-01	0.1044E 02	0.2943E-04	0.3912E 00	0.6087E 00	0.1609E 01
0.6100E 01	0.1795E-03	0.2386E 01	0.3713E 01		
0.1000E-01	0.1046E 02	0.2732E-04	0.3803E 00	0.6196E 00	0.1620E 01
0.6053E 01	0.1654E-03	0.2302E 01	0.3751E 01		
0.1000E-01	0.1048E 02	0.2535E-04	0.3695E 00	0.6304E 00	0.1630E 01
0.6007E 01	0.1523E-03	0.2220E 01	0.3787E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1050E 02	0.2351E-04	0.3589E 00	0.6411E 00	0.1641E 01
0.5962E 01	0.1402E-03	0.2140E 01	0.3822E 01		
0.1000E-01	0.1052E 02	0.2179E-04	0.3483E 00	0.6516E 00	0.1652E 01
0.5918E 01	0.1290E-03	0.2062E 01	0.3856E 01		
0.1000E-01	0.1054E 02	0.2019E-04	0.3380E 00	0.6620E 00	0.1662E 01
0.5875E 01	0.1186E-03	0.1986E 01	0.3889E 01		
0.1000E-01	0.1056E 02	0.1870E-04	0.3277E 00	0.6722E 00	0.1672E 01
0.5832E 01	0.1091E-03	0.1911E 01	0.3921E 01		
0.1000E-01	0.1058E 02	0.1731E-04	0.3177E 00	0.6823E 00	0.1682E 01
0.5790E 01	0.1002E-03	0.1840E 01	0.3951E 01		
0.1000E-01	0.1060E 02	0.1602E-04	0.3078E 00	0.6922E 00	0.1692E 01
0.5749E 01	0.9208E-04	0.1770E 01	0.3980E 01		
0.1000E-01	0.1062E 02	0.1481E-04	0.2981E 00	0.7019E 00	0.1702E 01
0.5709E 01	0.8456E-04	0.1702E 01	0.4007E 01		
0.1000E-01	0.1064E 02	0.1369E-04	0.2885E 00	0.7115E 00	0.1711E 01
0.5669E 01	0.7763E-04	0.1636E 01	0.4034E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1066E 02	0.1265E-04	0.2792E 00	0.7208E 00	0.1721E 01
0.5630E 01	0.7124E-04	0.1572E 01	0.4059E 01		
0.1000E-01	0.1068E 02	0.1169E-04	0.2700E 00	0.7300E 00	0.1730E 01
0.5592E 01	0.6535E-04	0.1510E 01	0.4082E 01		
0.1000E-01	0.1070E 02	0.1079E-04	0.2610E 00	0.7390E 00	0.1739E 01
0.5554E 01	0.5992E-04	0.1450E 01	0.4105E 01		
0.1000E-01	0.1072E 02	0.9957E-05	0.2522E 00	0.7478E 00	0.1748E 01
0.5517E 01	0.5493E-04	0.1392E 01	0.4126E 01		
0.1000E-01	0.1074E 02	0.9185E-05	0.2436E 00	0.7564E 00	0.1756E 01
0.5481E 01	0.5034E-04	0.1335E 01	0.4145E 01		
0.1000E-01	0.1076E 02	0.8469E-05	0.2353E 00	0.7647E 00	0.1765E 01
0.5445E 01	0.4611E-04	0.1281E 01	0.4164E 01		
0.1000E-01	0.1078E 02	0.7807E-05	0.2271E 00	0.7729E 00	0.1773E 01
0.5409E 01	0.4223E-04	0.1228E 01	0.4181E 01		
0.1000E-01	0.1080E 02	0.7193E-05	0.2191E 00	0.7809E 00	0.1781E 01
0.5374E 01	0.3866E-04	0.1177E 01	0.4197E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
	CT	A0CT	A1CT	A2CT	
0.1000E-01	0.1082E 02	0.6626E-05	0.2113E 00	0.7887E 00	0.1789E 01
	0.5339E 01	0.3538E-04	0.1128E 01	0.4211E 01	
0.1000E-01	0.1084E 02	0.6101E-05	0.2037E 00	0.7963E 00	0.1796E 01
	0.5305E 01	0.3237E-04	0.1081E 01	0.4224E 01	
0.1000E-01	0.1086E 02	0.5616E-05	0.1964E 00	0.8036E 00	0.1804E 01
	0.5271E 01	0.2960E-04	0.1035E 01	0.4236E 01	
0.1000E-01	0.1088E 02	0.5167E-05	0.1892E 00	0.8108E 00	0.1811E 01
	0.5237E 01	0.2706E-04	0.9909E 00	0.4246E 01	
0.1000E-01	0.1090E 02	0.4753E-05	0.1822E 00	0.8178E 00	0.1818E 01
	0.5204E 01	0.2473E-04	0.9483E 00	0.4255E 01	
0.1000E-01	0.1092E 02	0.4371E-05	0.1755E 00	0.8245E 00	0.1825E 01
	0.5171E 01	0.2260E-04	0.9073E 00	0.4263E 01	
0.1000E-01	0.1094E 02	0.4018E-05	0.1689E 00	0.8311E 00	0.1831E 01
	0.5137E 01	0.2064E-04	0.8678E 00	0.4270E 01	
0.1000E-01	0.1096E 02	0.3692E-05	0.1625E 00	0.8374E 00	0.1837E 01
	0.5104E 01	0.1885E-04	0.8297E 00	0.4275E 01	

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1098E 02	0.3392E-05	0.1564E 00	0.8436E 00	0.1844E 01
0.5071E 01	0.1720E-04	0.7931E 00	0.4278E 01		
0.1000E-01	0.1100E 02	0.3116E-05	0.1504E 00	0.8496E 00	0.1850E 01
0.5039E 01	0.1570E-04	0.7578E 00	0.4281E 01		
0.1000E-01	0.1102E 02	0.2861E-05	0.1446E 00	0.8554E 00	0.1855E 01
0.5006E 01	0.1432E-04	0.7238E 00	0.4282E 01		
0.1000E-01	0.1104E 02	0.2626E-05	0.1390E 00	0.8610E 00	0.1861E 01
0.4972E 01	0.1306E-04	0.6912E 00	0.4281E 01		
0.1000E-01	0.1106E 02	0.2410E-05	0.1336E 00	0.8664E 00	0.1866E 01
0.4939E 01	0.1191E-04	0.6598E 00	0.4279E 01		
0.1000E-01	0.1108E 02	0.2212E-05	0.1283E 00	0.8717E 00	0.1872E 01
0.4906E 01	0.1085E-04	0.6296E 00	0.4276E 01		
0.1000E-01	0.1110E 02	0.2029E-05	0.1233E 00	0.8767E 00	0.1877E 01
0.4872E 01	0.9884E-05	0.6006E 00	0.4271E 01		
0.1000E-01	0.1112E 02	0.1861E-05	0.1184E 00	0.8816E 00	0.1882E 01
0.4838E 01	0.9001E-05	0.5727E 00	0.4265E 01		

A1K	PH	ALPHA0	ALPHA1	ALPHA2	ALPHA3
CT	A0CT	A1CT	A2CT		
0.1000E-01	0.1114E 02	0.1706E-05	0.1137E 00	0.8863E 00	0.1886E 01
0.4803E 01	0.8194E-05	0.5459E 00	0.4257E 01		
0.1000E-01	0.1116E 02	0.1564E-05	0.1091E 00	0.8909E 00	0.1891E 01
0.4768E 01	0.7457E-05	0.5202E 00	0.4248E 01		
0.1000E-01	0.1118E 02	0.1433E-05	0.1047E 00	0.8953E 00	0.1895E 01
0.4733E 01	0.6783E-05	0.4956E 00	0.4237E 01		
0.1000E-01	0.1120E 02	0.1313E-05	0.1005E 00	0.8995E 00	0.1900E 01
0.4697E 01	0.6168E-05	0.4719E 00	0.4225E 01		